UNIVERSITY OF TWENTE.

Isala klinieken

# Insights in the effects of an admissions schedule on the wards


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# Management summary


## Background

In Isala Klinieken the processes at the wards are negatively affected by other processes in the hospital. The admissions schedule is supposed to be the main reason for this. The department Patient Logistics within Isala Klinieken already performed research about this on a tactical level. The current research takes the next step by broadening the scope to the operational offline level. The objective of this research is:

*Generating insights in the effects of operational offline scheduling decisions made for hospital admissions on the capacity planning processes at the wards.*

## Approach

To generate these insights a tool is (partly) developed to show the admissions planners the quality of their schedule. This research consists of multiple steps. First, we constructed a list of performance measures which are important for the wards and should therefore be shown to the admissions planners. We based this list on interviews and a survey on all hierarchical levels within Isala Klinieken. This resulted in a long list of performance measures. Therefore, we reduced the list by using evaluation criteria and by looking at the importance based on the interviews and the survey. Secondly, we interviewed multiple planners and the department Patient Logistics to determine how these performance measures should be displayed for the admissions planners. The third part of this research focused on how to forecast the information needed to calculate the performance measures. We partly based this on models from literature. Finally, we developed part of the tool according to the software development method Extreme Programming.

## Conclusions

The performance measures that should be shown to the admissions planners are:

- Average utilization per ward
- Variability in the number of used beds over the week
- Staff productivity
- Variability in amount of work during the day
- Constant pattern in amount of work over the week
- Variability in admissions during the day
- Variability in admissions over the week
- Staff availability
- Overutilization per ward
- Overutilization on certain moments of the day

A further requirement of the tool is that it should summarize these measures into a rating for the total quality of the admissions schedule. Next to this the tool should show the trends of the total quality and of the performance measures. Another important requirement for the tool is that it should be flexible. This is translated into a possibility for admissions planners to change multiple settings in the tool. During this research we developed part of the tool, namely the results for the admissions over the week and for the overutilization. For the calculations of the overutilization we build upon the tactical model of Smeenk (2011).

## Recommendations

We recommend Isala Klinieken to continue developing the proposed tool and to implement it. Next to this, we recommend changing the focus in the organization from the operating rooms more to the wards. Our final recommendation is to let the admissions for one ward be scheduled by one admissions planner or scheduling team. Currently the admissions are scheduled per specialism. Especially for the new hospital with larger wards this would mean that multiple planners schedule for the same ward.

Topics for future research are:

- how to change the focus within Isala Klinieken from the OR department to the wards
- generating insights in other resources than wards, like for example ORs and IC
- examining if there is correlation between the performance measures
- improving the input for the tool
- improving the method for integrating the performance measures into a rating for the total quality of the schedule

# Management samenvatting (Dutch)

## Achtergrond

Binnen de Isala Klinieken worden de processen op de verpleegafdelingen negatief beïnvloed door andere processen binnen het ziekenhuis. De opnameplanning wordt gezien als de voornaamste reden hiervoor. De afdeling Patiënten logistiek van de Isala Klinieken heeft hier al onderzoek naar gedaan op een tactisch niveau. Dit onderzoek gaat hiermee verder op het operationeel offline niveau. Het doel van dit onderzoek is:

*Het genereren van inzichten in de effecten van operationeel offline beslissingen met betrekking tot de opnameplanning op de planningsprocessen op de verpleegafdelingen.*

## Aanpak

Voor het genereren van deze inzichten is een tool gecreëerd die de planners de kwaliteit van hun planning laat zien. Dit onderzoek bestaat uit een aantal stappen. Ten eerste hebben we een lijst opgesteld met belangrijke indicatoren voor de verpleegafdelingen die getoond moeten worden aan de opnameplanners. Deze lijst hebben we gebaseerd op interviews en een enquête op alle hiërarchische niveaus binnen de Isala Klinieken. Dit resulteerde in een lange lijst met prestatie indicatoren. Daarom hebben we deze lijst gereduceerd door gebruik te maken van evaluatie criteria en door te kijken naar het belang van de indicatoren blijkend uit de interviews en de enquête. Ten tweede hebben we meerdere planners en de afdeling Patiënten logistiek geïnterviewd om te bepalen hoe deze prestatie indicatoren weergegeven moeten worden aan de opnameplanners. Het derde deel van het onderzoek richt zich op hoe de informatie die nodig is voor het berekenen van de indicatoren kan worden voorspeld. Dit baseren we gedeeltelijk op modellen uit de literatuur. Uiteindelijk hebben we een deel van de tool ontwikkeld door gebruik te maken van de software ontwikkelingsmethode Extreme Programming.

## Conclusies

De prestatie indicatoren die aan de opname planners moeten worden getoond, zijn:

- Gemiddelde bezetting per verpleegafdeling
- Variabiliteit in het aantal gebruikte bedden over de week
- Productiviteit personeel
- Variabiliteit in voorhanden werk gedurende de dag
- Constant patroon in voorhanden werk over de week
- Variabiliteit in opnames gedurende de dag
- Variabiliteit in opnames over de week
- Beschikbaarheid personeel
- Overbezetting per verpleegafdeling
- Overbezetting op bepaalde momenten van de dag

Een extra eis aan de tool is dat het deze indicatoren moet samenvatten in een cijfer voor de totale kwaliteit van de opnameplanning. Hiernaast moet de tool een trend voor de totale kwaliteit en voor de prestatie indicatoren weergeven. Een andere belangrijke eis is dat de tool flexibel is. Dit is vertaald in een mogelijkheid voor de opnameplanners om meerdere instellingen in de tool aan te passen. Tijdens dit onderzoek hebben we een deel van de tool ontwikkeld, namelijk de resultaten voor opnames over de week en voor overbezetting. Voor de berekeningen van overbezetting hebben we het tactische model van Smeenk (2011) verder ontwikkeld.

### Aanbevelingen

We bevelen Isala Klinieken aan om door te gaan met het ontwikkelen van de tool en deze te implementeren. Daarnaast bevelen we aan om de focus binnen de organisatie te verplaatsen van de operatiekamers meer richting de verpleegafdelingen. Onze laatste aanbeveling is om de opnames voor één afdeling te laten plannen door één opnameplanner of team. Op dit moment worden de opnames gepland per specialisme. Vooral voor het nieuwe ziekenhuis met grotere verpleegafdelingen zal dit betekenen dat meerdere planners voor dezelfde afdeling plannen.

Onderwerpen voor verder onderzoek zijn:

- hoe de focus binnen Isala Klinieken moet worden verplaatst van de OK afdeling naar de verpleegafdelingen
- het genereren van inzichten in andere middelen dan de verpleegafdeling, zoals bijvoorbeeld de OKs en de IC
- onderzoeken of er correlatie is tussen de indicatoren
- het verbeteren van de invoer van de tool
- het verbeteren van de methode voor het samenvoegen van de prestatie indicatoren in een cijfer voor de totale kwaliteit van de planning

# Preface

When I started my study Industrial Engineering and Management six years ago I never expected to end up in health care. After getting acquainted with this fascinating discipline by chance during my Bachelor thesis, I couldn't let go of it. When searching for a Master thesis, it was clear that it should be in a hospital. The enthusiasm of Erwin and Ingrid about Isala Klinieken and the ideal location of Zwolle made the choice for Isala Klinieken easy. A few months later I moved to Zwolle and I did not regret it for even a minute.

I want to use this opportunity to thank some people for their help and support during these last few months. First of all I want to thank Bernd. Your innovative ideas and our interesting conversations brought this research to a higher level. Every problem could be solved with one of our discussions. What made my time within Isala extra special were the opportunities you gave me to experience health care logistics in practice. Thank you for that. I also want to thank all employees of Isala Klinieken that were involved during my research. Everyone was always prepared to help me and to answer my questions, this made working on my thesis even more fun.

Of course I also want to thank my supervisors from the university, Ingrid and Erwin. You gave me the freedom to make it my own research. Although we only had a few appointments, our conversations always helped me to make a large step forward at the right moment. I do not only want to thank you for your help during my Master thesis, but also for our collaboration before that. I learned a lot from you during my courses and as a student assistant. Thank you both for those opportunities.

Last but not least, I want to thank my family and my friends for the support they gave me during my study. It was a rollercoaster of events and emotions and you were always there to fall back on.

I hope you will enjoy reading my report just as much as I did writing it.

Annemaaike Hooijsma

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# Contents

# Chapter 1 - Introduction

Usually a patient has to go through several steps for his/her treatment in a hospital. This process is called the clinical pathway. For some patients staying at the ward is part of this pathway. Wards interact a lot with other departments, for example the operating room (OR) department. These other departments have a large influence on the wards. Despite of this clear interaction between departments, most research in healthcare logistics focuses on a single department (Vanberkel, Boucherie, Hans, Hurink, & Litvak, 2009) and often this single department is not the ward (Cardoen, Demeulemeester, & Beliën, 2010). This means that improvements are made at other departments and that wards just have to cope with these changes. This contradicts with the fact that staffing at the wards is an expensive resource for a hospital (Hurst, 2010) and sufficient staffing is important because it has a large influence on the mortality rate (Aiken, Clarke, Sloane, Sochalski, & Silber, 2002) and on patient and employee satisfaction. For these reasons Isala Klinieken in Zwolle initiated research on the interaction between wards and, among others, the OR department. With this master thesis we hope to contribute to this research line.

Section 1.1 describes the context of the research, Isala Klinieken in Zwolle. Section 1.2, gives a description of the problem investigated in this research. From this description we determine the objective of the research in Section 1.3. This chapter ends with the research questions that will be answered during the rest of the report.

## 1.1 Isala Klinieken Zwolle

The context in which this research takes place is Isala Klinieken in Zwolle. This is the largest top clinical hospital in the Netherlands. It has approximately 5.400 employees to support 260 medical specialists. In the hospital there are approximately 1000 beds available. With these resources Isala Klinieken helps more than 500.000 outpatients and 95.000 inpatients per year. The hospital has yearly revenues of 442 million euro. Next to treating patients Isala Klinieken also focuses on innovation, training and research. Isala Klinieken has two locations; these are Sophia and Weezenlanden. Next to that there are two outpatient clinics in Heerde and Kampen, two laboratories and a Diaconessenhuis Meppel (www.isala.nl/overisala, 2012).

Figure 1.1 - Logo Isala Klinieken

At the moment Isala Klinieken is building a new hospital in Zwolle at the location Sophia. In August 2013 the new hospital will be ready for use. Figure 1.2 shows an artist impression of the new building (www.isalabouwt.nl, 2012).

This research project is commissioned by the department Patient Logistics of Isala Klinieken. This department is concerned with the patient flow and capacity management in the hospital.

Figure 1.2 - Artist impression new hospital (source: http://www.isalabouwt.nl/isalabouwt/Structuur/Pages/default.aspx#x1)

## 1.2 Problem

This section describes the problem on which this research focuses. Subsection 1.2.1 gives the motivation for the research and Section 1.2.2 describes the problem in more detail.

### 1.2.1 Motivation

In Isala Klinieken the processes at the wards are negatively affected by the admissions schedule. One of the problems experienced is a high variability in the workload for nurses at the wards. According to Litvak et al. (2005) reducing unnecessary variability at wards will reduce the stress for patients and nurses and it will improve the safety and quality of care for patients. Large variability in the amount of work makes that the number of nurses that is actually needed, differs from the number that is scheduled. During some shifts there is not enough staff and during others there is too many. This will not only result in lower safety and quality at the wards but it also leads to frustrations, which in turn has its effects on the processes at the wards.

The amount of work at the ward originates from, among other things, the number of patients at the wards, the intensity of care of these patients and the number of admissions and discharges in a certain period of time. The number of patients, admissions and discharges are also used as measures in earlier research projects about this topic (Vanberkel, Boucherie, Hans, Hurink, Lent, & Harten, 2011a). The schedules for the ORs and for non-surgical treatments have a large influence on these variables and therefore also on the amount of work at the wards. A better interaction between the departments could reduce the variability in this.

At Isala Klinieken tools already exist for forecasting the amount of work based on an existing schedule. These forecasts are not used to improve the schedule. Therefore, it does not reduce variability and the wards still have to adapt to the schedules for the ORs and for non-surgical treatments. For the wards it is not always possible to adapt because of capacity (nurses and beds) and time restrictions. It would be better to also look at reducing the variability of the amount of work. Previous research at Isala Klinieken (Vlijm, 2011) focused on reducing the variability by making adjustments to the OR schedule on a tactical level. This research takes the next step by broadening the scope to other hierarchical levels and to other aspects of the processes at the wards.

### 1.2.2 Problem description

To give a more detailed description of the problem we use the framework for hospital planning and control from Hans et al. (2011). This framework is displayed in Table 1.1. The framework consists of some managerial areas and hierarchical levels. In the table an example is given for each combination. The area and level that our research focuses on are marked green in the table. Later in this section we explain these choices. Hans et al. (2011) give four managerial areas, these are:

- *Medical planning*
  This area is about medical decisions made in a hospital. It especially involves the decisions made by specialists and nurses.
- *Resource capacity planning*
  Resource capacity planning involves the planning of non-renewable resources, like staff and rooms. It also includes scheduling patients.

- *Materials planning*
  Next to non-renewable resources hospitals also use renewable resources, like blood, medicines and equipment that are only used once. Planning of these resources belongs to the materials planning area.
- *Financial planning*
  The final managerial area is financial planning. This includes decisions about costs and revenues of the hospital.

From the motivation described above we can conclude that this research focuses on resource capacity planning. This area includes scheduling for the ORs and non-surgical treatments and staffing at the wards.

Hans et al. (2011) also give four hierarchical levels. The levels are:

- *Strategic level*
  The strategic level includes decisions made for the long term.
- *Tactical level*
  Medium term decisions are made at the tactical level. These decisions do not yet concern actual patients.
- *Operational offline level*
  At the operational offline level decisions are made for the short term, but the decisions are still made in advance. In contrast to the tactical level, decisions at this level do include actual patients.
- *Operational online level*
  The decisions made at the operational online level are also for the short term. However, these are not made in advance, but during the process.

**Table 1.1 - Framework for hospital planning and control**

| | Medical planning | Resource capacity planning | Materials planning | Financial planning |
|---|---|---|---|---|
| **Strategic** | Research | Case mix planning | Warehouse design | Investment plans |
| **Tactical** | Treatment selection | Block planning, staffing | Supplier selection | Budget allocation |
| **Operational offline** | Diagnosis | Appointment scheduling | Materials purchasing | Cash flow analysis |
| **Operational online** | Triage | Emergency coordination | Rush ordering | Billing complications |

To decide which hierarchical level to focus on, we compare the current situation of the resource capacity planning area with the desired situation. Figure 1.3 shows the current situation. We divide the resource capacity planning in two parts, the ORs and non-surgical treatments and the wards. For the ORs and non-surgical treatments the focus of the research is on scheduling patients and not on other resources needed for the treatments. The capacity planning processes at the wards can be divided in staffing and bed planning.

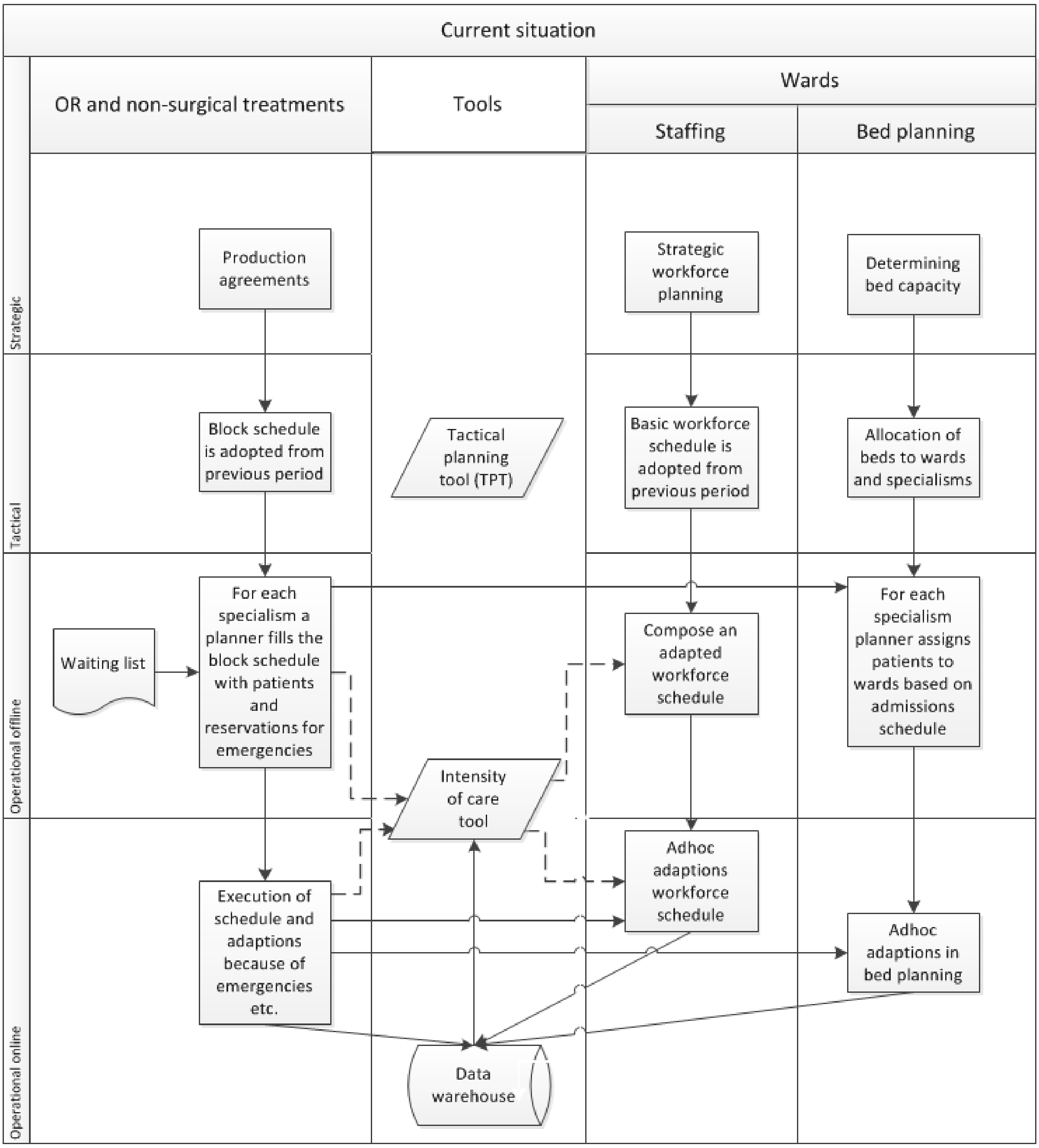


Figure 1.3 - Current situation

At a strategic level production agreements are made for the treatments. At the wards the bed capacity is determined and strategic decisions for the workforce are made, like for example the number of nurses to hire.

In the current situation not many changes are made on a tactical level. Block schedules and a basic workforce schedule are used, but these are often adopted from the previous period. Also the allocation of beds to the wards and specialisms is almost never changed. Isala Klinieken has a tactical planning tool (TPT), which was constructed by Ronald Vlijm (2011). This tool is based on the model of Vanberkel et al. (2011a). The tool can predict the amount of work at the wards based on the OR block schedule and it can make improvements to the block schedule based on this. This tool is not yet used in the organization.

At the operational offline level the planners for the different specialties make the admissions schedules, which means filling the block schedules with patients and reservations for emergencies. Based on this schedule the planner assigns the patients to the wards. At this level the basic workforce schedule of the wards is adapted. Isala Klinieken has built an intensity of care tool that can predict the amount of work at the wards based on an existing admissions schedule and on the current ward occupancy. In this it takes into account the expected intensity of care of the patients. At some wards this tool is used to determine the workforce schedule on the offline and online level.

At the operational online level changes are made in the schedule for the treatments and based on these changes the workforce schedule and the bed planning of the wards is adapted. During execution of the schedules data is stored in the data warehouse. This data is often only used for decisions at a strategic and tactical level.

A lot of improvements are possible for these processes. The desired situation according to Isala Klinieken is displayed in Figure 1.4. In this figure improvements are marked green. We describe the improvements per hierarchical level:

- *Strategic level*
  An improvement at the strategic level is that the production agreements are considered more when performing the strategic workforce planning and when determining the bed capacity. But also the other way around is important, when production agreements are made constraints concerning the workforce and bed capacity should be considered.
- *Tactical level*
  Previous projects of students at Isala Klinieken often focused on this level. Therefore there are already some tools available for improvements here. The main aspect is the tactical planning tool that can predict the amount of work at the wards based on the OR block schedule and can improve the block schedule based on this. A large improvement at the tactical level is using this tool every few months to evaluate the block schedule, the basic workforce schedule and the bed allocation. Further improvements at this level would be improving this tactical planning tool. It is, for example not clear whether the objective that this tool uses, is the right one.
- *Operational offline level*
  At this level there already exists an experimental intensity of care tool. However, this tool is currently only used by a few wards, in the desired situation the tool is used for determining the workforce schedules of all wards. The admissions schedules are now determined based on the block schedule and the waiting lists. Effects of the schedule for the ORs and non-surgical treatments are partly clear for the planner, because these are the main resources they use. However, the effects for the wards are not considered at all when making the admissions schedule. Therefore, an improvement at the operational offline level would be to construct a tool that gives the planner insights in the effects of the constructed schedule. Although effects for the ORs and non-surgical treatments are already more clear than those for the wards, the tool could also give some more insights in these effects. It could for example calculate a probability of overtime for a given schedule.

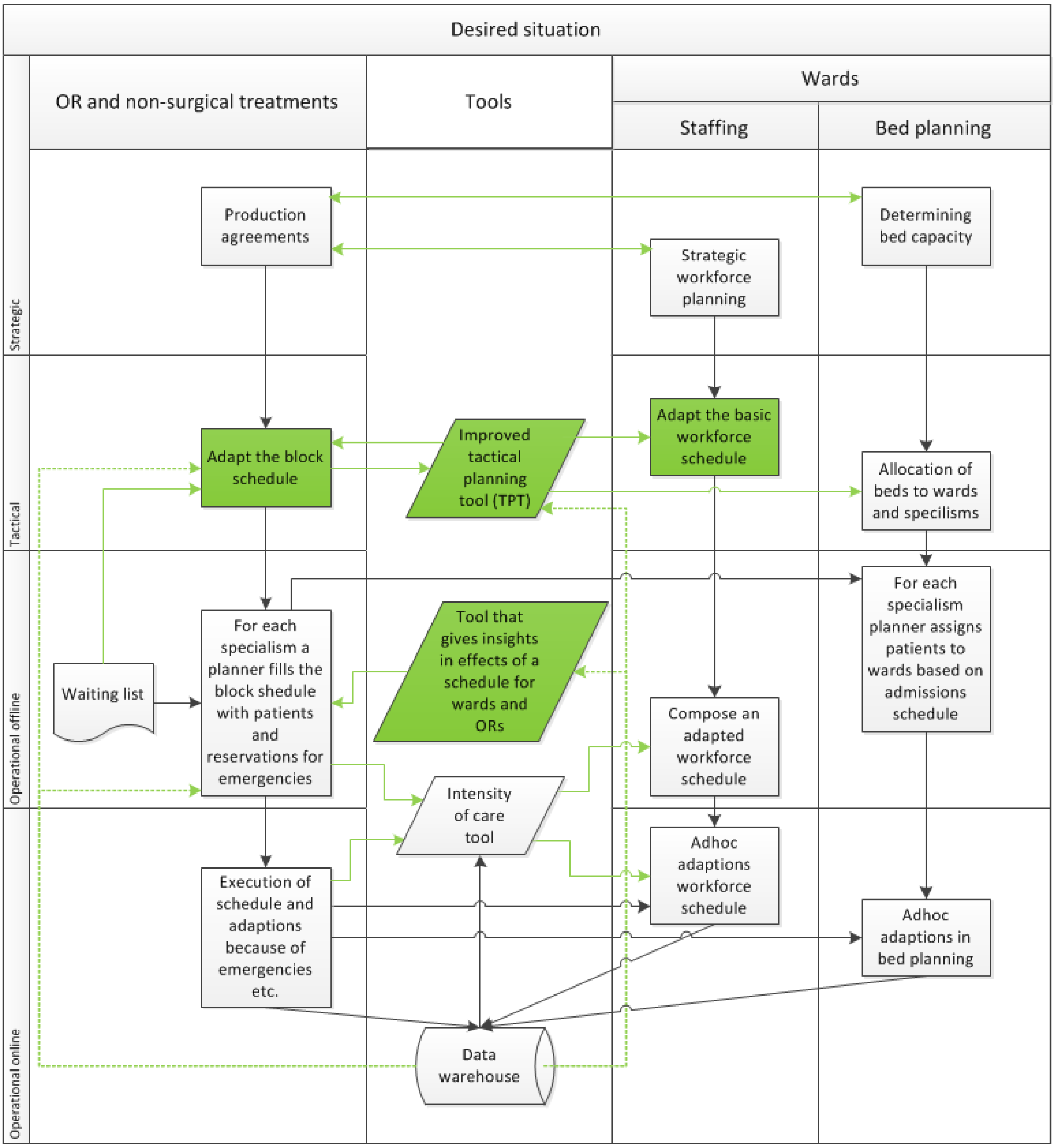


Figure 1.4 - Desired situation

- *Operational online level*

  Data from the data warehouse is now mainly used for decisions at the strategic and tactical level. It would be better to learn from results of previous periods also on other levels. Feedback should be given to the planners and to the people that are responsible for the block schedules. Besides, the data should be used for improving the different tools.

The figure for the desired situation does not show improvements in the processes at the operational online level, it only shows improvements for feedback on this level. At this level the interaction between the processes could be investigated. However, it is not yet clear whether improvements are possible here, because you cannot influence emergencies much. It is also expected that improvements at other levels are more urgent. Therefore, in this research we do not further look into possible improvements for the processes at the operational online level.

We will focus on the operational offline hierarchical level. Because of the new building for the hospital, current projects especially focus on decisions on the strategic and tactical level. For example, the bed capacity and the allocation of beds to the wards are determined now. These decisions will not have the expected optimal results when the capacity planning processes at the lower levels and in other areas do not perform sufficiently. At the tactical level Isala Klinieken already did a lot of research. Although some adjustments might be necessary, the existing tactical planning tool can already lead to large improvements at this level. Therefore, a focus on the operational offline planning is more urgent now. It is expected that focusing on the tool on the operational offline level leads to the best results. The feedback from the data warehouse is also important, but this is only possible when processes at higher levels are performing adequately.

The tool on the operational offline level should give the planner insights in the effects of an admissions schedule on the wards, the ORs and non-surgical treatments. However, research necessary for these three aspects is very different, because different performance measures should be used and other departments of the hospital are involved. To make sure the research does not become too broad, we only focus on the wards. The planner already sees some effects for the ORs and non-surgical treatments, because that is the main resource they schedule. This is not the case for wards. Therefore it is now more important to focus on these insights.

To get from a schedule to the insights different steps are necessary, these steps are shown in Figure 1.5. The first step is to forecast what will happen at a ward when applying a certain schedule. The next step is calculating performance measures from these forecasts and the final step is displaying it to the admissions planners.

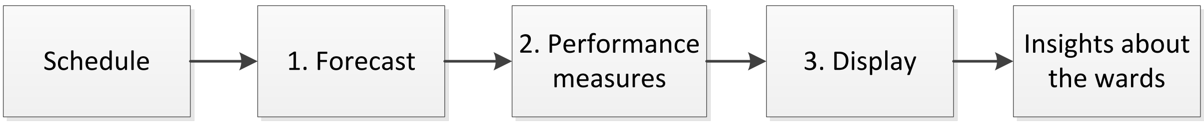


Figure 1.5 - Steps in the process of generating insights

## 1.3 Research objective and research questions

Based on the problem description we formulate the following research objective:

| |
|---|
| Generating insights in the effects of operational offline scheduling decisions made for hospital admissions on the capacity planning processes at the wards. |

In order to reach this objective we answer the following research questions throughout this thesis:

1. *How are the current capacity planning processes for the ORs, the non-surgical treatments and the wards organized and how are they planned and controlled?*
   The first step in the research is finding out how the current processes are organized. A short description is already given in Section 1.2.2. Chapter 2 expands this description.

2. *What are performance measures for an admissions schedule for the hospital that need to be considered when looking at the capacity planning processes at the wards?*
   The research objective is to generate insights, but it is not yet clear which insights are important. These insights should be based on performance measures that are important for the wards, on an organizational level, and can be influenced by the admissions schedule on an operational offline level. Finding out what these performance measures are is needed for the second step in Figure 1.5. Chapter 3 describes these performance measures and also gives the current performance of the wards based on these measures.

3. *What are the expectations of the organization for the proposed tool?*
   The research should result in insights for the planners. How should these insights be presented according to the department Patient Logistics and the planners themselves? Answering this question is important for the third step in Figure 1.5. Chapter 4 gives a conceptual model of the tool.

4. *Which models have been proposed in literature for generating insights in the effects of an admissions schedule?*
   In Chapter 5 we look for existing literature about models that combine admissions schedules with the processes at the wards. We could use these models as a starting point for the forecasting step of our tool.

5. *Which models are suitable to be used as the basis for the proposed tool and how can these models be adapted to be applicable in Isala Klinieken?*
   Previous research questions give models from literature and restrictions from practice for the tool. Chapter 6 combines this and gives a description of the proposed tool. Because of time constraints we develop only part of the proposed tool during this research.

6. *What are the issues when implementing the proposed tool?*
   The final step in the process is implementing the proposed tool. We will not be involved much in the implementation. However, in Chapter 7 we do give a proposal for the implementation phase.

7. *What conclusions and recommendations follow from the research?*
   Finally, Chapter 8 gives the conclusions and recommendations that we can address based on this research.

# Chapter 2 - Context analysis

A problem cannot be solved without knowing its context. That is why this chapter focuses on analyzing the context of the problem that is described in the previous chapter. In Subsection 2.1 the process flow of the patient through the hospital is addressed. This process flow needs to be planned and controlled. Subsection 2.2 discusses these aspects.

## 2.1 Process

This section describes the process flow of a patient through the hospital. There are a lot of possibilities for this, but the focus in this research is on patients that will go to the ward in some point of the process. First we describe the different steps of the process flow and then we give some more information about these steps. At the moment Isala Klinieken is building a new hospital, in this hospital some of the characteristics of the process will change, we describe these changes at the end of this section.

When a patient arrives at the hospital he/she first goes to the outpatient department (possibly after a reference from the general practitioner) or the emergency department. When the patient arrives at the outpatient department, the patient has an appointment with a specialist. The specialist determines whether the patient needs treatment and whether this is urgent. If it is urgent, the patient goes to the ward directly, otherwise the patient is put on the waiting list and an admission is scheduled when capacity becomes available. At the day of the surgery or treatment, the patient first goes to the ward. From the ward, he/she goes to the OR department or to a non-surgical department. At the OR department the patient is first kept in holding and then he/she is prepared for surgery. After the treatment he/she has to go into recovery. Finally the patient goes back to the ward, or first to the intensive care and then to the ward, until he/she is ready to leave the hospital. This total process flow is shown in Figure 2.1.

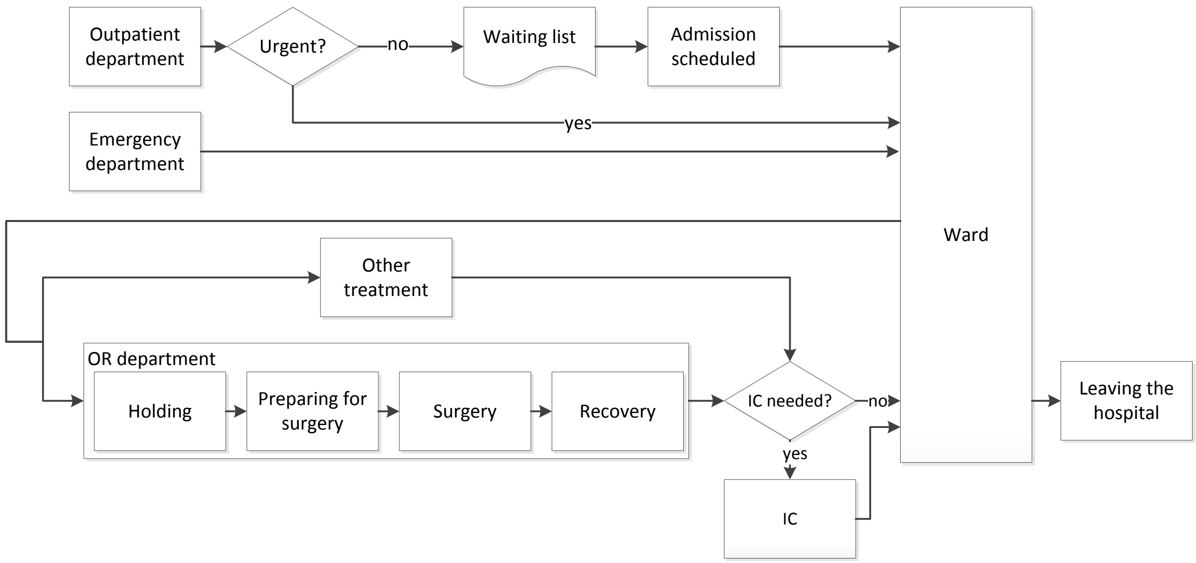


Figure 2.1 - Process flow patient

The hospital has a lot of different outpatient departments. Every outpatient department belongs to a specialism and each specialism has certain wards that they preferably use. The treatments that are performed by a specialism can be surgical or non-surgical. Table 2.1 gives an overview of the specialisms of Isala Klinieken. It also gives their main location, which wards they preferably use, which percentage of all admissions they cause, which percentage of their admitted patients needs a surgical treatment and which percentage is emergencies. Both day care patients and clinical patients are included. Patients that only go to the emergency department or acute admissions ward are not considered as admissions here.

**Table 2.1 - Overview specialisms (source: iZis, 2011, n = 80178 patients)**

| Specialism | Location | Preferred wards | % of all admis-sions | % of admis-sions that needs OR | Emergency % of admissions |
|---|---|---|---:|---:|---:|
| Anesthesiology | Weezenlanden | A2, A5, A6 | 1,5% | 98% | 3% |
| Cardiology | Weezenlanden | B1, B1IC, B3, B5, B6 | 10,1% | 12% | 48% |
| Ear, nose and throat surgery (ENT) | Sophia and Weezenlanden | SZ\|A1, WL\|A2, WL\|A2K | 4,4% | 97% | 3% |
| Ophthalmology | Weezenlanden | A2 | 5,1% | 94% | 4% |
| Gastroenterology | Sophia | B1, M3 | 11,5% | 2% | 51% |
| General surgery | Sophia | A1, A1P, B3, B4, B5 | 8,0% | 77% | 33% |
| Gynecology | Sophia | A1, A5, A5C, A6, A6W, B5G | 9,2% | 40% | 44% |
| Internal medicine | Sophia | A1P, A3, B2, B6, M5 | 16,0% | 4% | 51% |
| Lung medicine | Weezenlanden | A2, B4, B6 | 5,1% | 3% | 48% |
| Neurology | Weezenlanden | A2, A5, A6 | 5,0% | 8% | 49% |
| Neurosurgery | Sophia | D3, IC | 1,9% | 91% | 10% |
| Jaw surgery | Weezenlanden | A2, A2K | 1,1% | 98% | 7% |
| Orthopedics | Sophia and Weezenlanden | SZ\|B3, WL\|A2, WL\|A4 | 5,4% | 90% | 17% |
| Pediatrics | Sophia | A5W, A6W, K1B, K2, K3, NEO | 5,5% | 5% | 49% |
| Plastic surgery | Sophia | A1, B3, K3 | 3,7% | 98% | 12% |
| Psychiatry | Sophia | SZ\|H0 | 0,7% | 14% | 50% |
| Radiotherapy | Sophia | B1 | 0,02% | 8% | 77% |
| Rheumatology | Weezenlanden | A2, A5 | 0,7% | 11% | 38% |
| Special dental surgery | Weezenlanden | A2, A2K | 0,4% | 99% | 0,3% |
| Thoracic surgery | Weezenlanden | A7, IC | 1,5% | 95% | 7% |
| Urology | Weezenlanden | A2, A2K, A5 | 2,8% | 65% | 21% |

As already can be seen in Table 2.1, the hospital has a lot of different wards. Tables 2.2 and 2.3 give an overview of these wards per location. The wards are different because of the specialisms that use them, but also the function of the wards differs. The wards can be divided into day care wards and clinical wards. Patients that only need to stay in the hospital on the day of their treatment often stay at the day care wards. These wards are closed during the night and the weekend. Patients that need to stay in the hospital longer go to the clinical wards. At Isala Klinieken this division is not that strict, there are also day care patients that go to a clinical ward. Clinical wards can be divided into intensive and specific wards, general nursing wards and psychiatric wards.

**Table 2.2 - Overview wards location Sophia (source: iZis, 2011, n = 49421 patients)**

| Ward | Number of beds | Day care / Clinical | Specialisms |
|---|---|---|---|
| A1 | 10 | Day care | Gynecology, Ear, nose and throat surgery, Plastic surgery, General surgery |
| A1P | 15 | Clinical (general) | Internal medicine, General surgery |
| A3 | 40 | Clinical (general) | Internal medicine |
| A5 | 18 | Clinical (intensive and specific) | Gynecology |
| A5C | 9 | Clinical (intensive and specific) | Gynecology |
| A5W | 8 | Clinical (intensive and specific) | Pediatrics |
| A6 | 17 | Clinical (intensive and specific) | Gynecology |
| A6W | 17 | Clinical (intensive and specific) | Gynecology, Pediatrics |
| B1 | 41 | Clinical (general) | Radiotherapy, Gastroenterology |
| B2 | 41 | Clinical (general) | Internal medicine |
| B3 | 42 | Clinical (general) | General surgery, Orthopedics, Plastic surgery |
| B4 | 42 | Clinical (general) | General surgery |
| B5 | 11 | Clinical (general) | General surgery |
| B5G | 17 | Clinical (general) | Gynecology |
| B6 | 23 | Clinical (general) | Internal medicine |
| D3 | 30 | Clinical (general) | Neurosurgery |
| H0 | 27 | Clinical (psychiatric) | Psychiatry |
| IC | 22 | Clinical (intensive and specific) | Neurosurgery |
| K1B | 16 | Clinical (intensive and specific) | Pediatrics |
| K2 | 8 | Day care | Pediatrics |
| K3 | 30 | Clinical (intensive and specific) | Pediatrics, Plastic surgery |
| M3 | 12 | Day care | Gastroenterology |
| M5 | 12 | Day care | Internal medicine |
| NEO | 14 | Clinical (intensive and specific) | Pediatrics |

Isala Klinieken has an OR department on both locations. At location Weezenlanden there are twelve ORs of which two are day care ORs. On these day care ORs only short surgeries are done on patients that can go home at the end of the day. Location Sophia has ten ORs. From these ten, two are day care ORs and one OR is completely reserved for emergencies. The capacities for the non-surgical treatments are less centralized and therefore too complex to describe here.

Table 2.3 - Overview wards location Weezenlanden (source: iZis, 2011, n = 31266 patients)

| Ward | Number of beds | Day care / Clinical | Specialisms |
|---|---|---|---|
| A2 | 41 | Clinical (general) | Anesthesiology, Special dental surgery, Jaw surgery, Ear, nose and throat surgery, Lung medicine, Neurology, Ophthalmology, Orthopedics, Rheumatology, Urology |
| A2K | 6 | Clinical (intensive and specific) | Special dental surgery, Jaw surgery, Ear, nose and throat surgery, Urology |
| A4 | 41 | Clinical (general) | Orthopedics |
| A5 | 44 | Clinical (general) | Anesthesiology, Neurology, Rheumatology, Urology |
| A6 | 35 | Clinical (general) | Anesthesiology, Neurology |
| A7 | 36 | Clinical (general) | Thoracic surgery |
| B1 | 12 | Clinical (intensive and specific) | Cardiology |
| B1IC | 4 | Clinical (intensive and specific) | Cardiology |
| B3 | 39 | Clinical (general) | Cardiology |
| B4 | 42 | Clinical (general) | Lung medicine |
| B5 | 39 | Clinical (general) | Cardiology |
| B6 | 41 | Clinical (general) | Cardiology, Lung medicine |
| EHH | 14 | Clinical (acute admissions) | Cardiology, Neurology, Urology |
| IC | 19 | Clinical (intensive and specific) | Thoracic surgery |

Isala Klinieken is building a new hospital at location Sophia. There will be fewer ORs in the new building. Now there are 22 ORs in total, in the new building there will be 14 ORs, but probably six ORs will be added in a treatment center.

It is expected that beds will become the main bottleneck. The new hospital will have approximately 780 beds instead of the 1000 beds that are now available. Although these 1000 beds are not all used now, some changes are needed to cope with having a capacity of only 780 beds. One of the changes is that the wards become larger. In that way it is easier to capture the variability in the number of beds needed (portfolio effect). Some of the current wards are shared between specialisms, but every specialism has its own beds and staff at the wards. In the new hospital specialisms also share beds and staff at a ward, such that a high number of beds needed for one specialism can be solved by a specialism that has a low requirement of beds at that moment.

Another large change in the new hospital is the acute admissions ward. At this ward emergency patients will be admitted. These patients stay at this ward for at most two days. During these days a diagnosis and a treatment are performed. In this period the patient is either discharged or transferred to the preferred ward. Because of this acute admission ward, there will be no unplanned admissions at clinical wards. At these wards there will still be some “emergency patients” admitted, but these admissions are known up to two days in advance. This makes admissions at the wards more predictable.

## 2.2 Planning and control

The process flow of the patient described in the previous section needs planning and controlling. Figure 1.3 in Chapter 1 already shows the general picture of the current planning and controlling of admissions, ward staffing and bed capacity. This section gives a more detailed description. This description is divided into the admissions schedule (Section 2.2.1) and scheduling of the wards (Section 2.2.2).

### 2.2.1 Admissions schedule

The admissions schedule is the schedule for ORs and non-surgical treatments. At the strategic level production agreements are made. These strategic decisions fall outside the scope of this research. The tactical level contains constructing block schedules. The block schedules are almost always adopted from the previous period. However, when the hospital moves to the new location next year this block schedule needs to be changed. The current block schedule for the ORs is displayed in appendix A.

On the operational offline level, the block schedules are filled with patients. This scheduling is decentralized, this means that every specialism has its own planner and makes its own admissions schedule. Because of the block schedules every specialism has its own periods in which it can schedule patients. A planner determines per block whether there are suitable patients in the waiting list. The schedules are based on, among other things, the waiting list, the wishes of the patient, restrictions regarding the specialist, OR etc. and sometimes also on the number of admissions at the wards. For some specialisms the schedule is made a few weeks in advance and the patients are notified approximately one week in advance. For other specialisms the admissions are scheduled immediately after the patient visited the specialist at the policlinic.

On the operational online level still some changes can be made in the schedule of the admissions. This is necessary because emergency treatments need to be added to the schedule. This is done by the planner of a specialism or by the OR planner, depending on how urgent the surgery is. In some cases surgeries need to be cancelled because of emergencies or surgeries that take longer than expected.

### 2.2.2 Ward scheduling

The wards have two main resources, beds and staff. This section discusses the planning of both resources. We start with the bed planning. At the strategic level it is determined how many beds are needed in total. This process falls out of the scope of this research, so we will not discuss it in more detail. At the next level, the tactical level, beds are allocated between wards and specialisms. This allocation almost never changes. However, large changes will soon be necessary for the new hospital. The precise allocation for the new hospital still has to be determined. At the operational offline level patients are assigned to the wards. This is done by the planner of the specialism. The planner does this at the same time as he/she makes the schedules for the treatments. These schedules are mainly based on the requirements of the treatments. So the planner does schedule patients at the wards, but often the capacity planning processes at the wards are not considered in this. At the operational online level the schedule changes because of emergencies and variability in length of stay. However, it also happens that the proposed schedule appears not to be feasible at the wards. This also leads to last minute changes.

The other part of planning at the wards is ward staffing. The strategic level of ward staffing includes decisions like how many nurses to hire. At the tactical level a basic workforce schedule is constructed. This schedule differs per ward and per specialism, because the nurses are generally not exchanged between specialisms. The basic workforce schedules do almost never change. They are often adopted from the previous period. The basic schedule is adapted a few days in advance; this is the operational offline level. These changes mostly mean that extra nurses are required. The hospital has nurses that can be flexibly deployed. These nurses are used at the departments that need extra staff. The operational offline schedule is based on the bed schedule for the next days. Next to that, a few wards use the intensity of care tool for determining the schedule. The intensity of care tool can predict the amount of work at the wards based on an existing admissions schedule and on the current ward occupancy. At the operational online level not many changes are possible. However, if it is really necessary last minute requests are made for extra nurses.

Now we know more about the context of the research we can start with the main research focus. The first step is to find out what defines a good admissions schedule. The next chapter describes the performance measures for this.

# Chapter 3 - Performance measures

This research delivers a tool that gives admissions planners insights in the effects of a schedule for the wards. The first question that arises is 'which insights should the tool give?'. Since the admissions planner should be able to improve the processes at the wards, the insights must be based on performance measures for the wards. Section 3.1 describes such measures from literature. Section 3.2 uses these measures from literature as a starting point to analyze which performance measures are important according to the hospital. These first two sections result in a long list of performance measures. Section 3.3 gives an overview of these measures. Presenting all these measures to the admissions planners will still not give much useful insights. Section 3.4 therefore reduces this list by evaluating the measures using evaluation criteria and the importance from the interviews and the survey. Before the performance measures can be used, you need to know how they should be measured. Section 3.5 describes this. Without knowing the performance of the current situation (before the tool is implemented) it is not possible to know whether the performance is improved by implementing the tool. Therefore, Section 3.6 describes the current performance.

## 3.1 Measures from literature

Literature about performance measures can be divided into two types: literature that gives relevant measures for this research and literature that discusses evaluation criteria for performance measures in general. This section is also divided according to this. Section 3.1.1 gives performance measures for wards while Section 3.1.2 discusses criteria on which these criteria can be evaluated.

### 3.1.1 Performance measures

Most overviews of performance criteria for wards come from literature reviews about health care logistics. All these literature reviews have a broader scope than wards alone. However, we only discuss measures for the wards, and then specifically the measures that can be influenced by an admissions schedule.

Li and Benton (1996) performed a literature review about health care performance measures used in literature. They do not mention a lot of measures that are interesting for the interaction between admissions schedules and wards. However, they do give a useful framework for displaying performance measures. They distinguish between internal and external measures, and cost/financial and quality performance. Internal measures are important for people inside the hospital and external measures are concerned with external stakeholders, for example an insurance company and patients. We evaluate performance measures from other literature reviews based on this framework.

Cardoen et al. (2010) analyze articles about operating room scheduling based on different aspects, one of these aspects is the performance criterion used. In the survey of Guerriero and Guido (2011) articles on different organizational levels are discussed. On the tactical level they discuss objectives used in articles and on the operational level they mention criteria used. Table 3.1 shows the criteria from these surveys in the framework of Li and Benton (1996).

Table 3.1 shows that literature does not mention any useful measures for external cost/financial performance. This is performance according to for example health insurance companies. This is logical because performance of the wards is less important for those organizations.

Table 3.1 - Performance measures from literature

| | Cost/financial performance | Quality performance |
|---|---|---|
| **Internal measures** | Underutilization [1,2]<br>Occupancy ratio [1,3]<br>Number of beds used [2]<br>Leveling wards/bed occupancy [1,2] | Number of nurses [2] |
| **External measures** | | Patient deferrals/ refusals [1]<br>Overutilization [1,2] |

[1] Cardoen et al. (2010)
[2] Guerriero and Guido (2011)
[3] Li and Benton (1996)

### 3.1.2 Criteria for measures

Literature also gives some guidelines for evaluating performance measures. One theory that is often used is the SMART-principle (Doran, 1981). Originally this theory was meant to evaluate objectives. However, in literature it is also used to evaluate performance indicators (Shabin & Mahbod, 2007). SMART stands for specific, measurable, attainable, realistic and time-bounded. Attainable means that the goal should be reachable, but that it is not too easy. This is not applicable when choosing performance measures, because there is not a goal to reach. The other criteria can be used for performance measures. Van Hoorn and Wendt (van Hoorn & Wendt, 2008) give another list of conditions that performance indicators should meet; indicators should be relevant, transparent, comparable, measurable, normative and possible to be influenced. There is some overlap with the SMART-principle. When combining these two principles, we get the following list of criteria which we will use to evaluate the performance measures:

- *Specific/Transparent*: the performance measure should be clear and easy to understand.
- *Relevant*: showing the performance measure should result in enough improvement for the wards compared to the effort needed to determine the measure.
- *Measurable*: it should be possible to monitor the performance measure. This means that needed data is available and that the effort needed to measure the indicators does not increase too much.
- *Comparable*: the measurement should be reliable and unambiguous such that a repetition of the measurement gives the same results.
- *Realistic/Can be influenced*: the admissions planners should be able to influence the performance measure.
- *Time bounded*: it should be possible to monitor the performance measure in a reasonable period of time.
- *Normative*: there should be the ability to compare the performance measure to a norm.

Every performance measure should comply with all these criteria. In Section 3.4 we evaluate the final list of performance measures based on these aspects.

## 3.2 Measures in practice

The previous section gives the measures mentioned in literature, but the measures used in Isala Klinieken might even be more important in this research. The opinion of the staff at the wards is of course very important in this, but also people in the other hierarchical levels of the organization should be involved. Section 3.2.1 describes what the strategic level uses as performance measures for the wards. Section 3.2.2 does this for the tactical level and finally Section 3.2.3 looks at it from the operational point of view.

### 3.2.1 Measures on a strategic level

The strategic level of Isala Klinieken consists of two members of the board of directors and three directors of operations. To find out which performance measures are important from a strategic point of view, we interviewed one of the directors of operations. From this interview it appears that the strategic level of Isala Klinieken is not much involved in processes and decisions at the wards. Their main responsibility for the specialisms is controlling the production according to the production agreements made. This could have consequences for the wards, but that is not their main focus (Hingst, 2012).

For the strategic level of the hospital utilization at the wards should be as high as possible. The admissions planner should have insights in this utilization of the wards. According to Hingst (2012) it is important that the planner always schedules a constant mixture of patients on a ward. It should be a constant mixture based on intensity of care and on length of stay, because it is expected that it is difficult to realize a high utilization if these mixtures are not constant. For the new hospital this constant mixture should also be taken into account when determining which specialisms will use a ward together (Hingst, 2012).

### 3.2.2 Measures on a tactical level

The strategic level of the hospital consists of only a few people, but the tactical level is already much larger. From this level we interviewed multiple people that are involved in measuring performance of the wards. These are the Capacity manager, the manager of the department Quality and Safety and some managers of specialisms. We chose three specialisms for the interviews that are very different based on size and use of the OR. A translation of the interview design is shown in Appendix B. We coded the aspects mentioned during the interview ourselves. Because we only interviewed a few people from the tactical level, the performance measures mentioned are probably not complete. To know which part of the measures we found, we used a Poisson model that was also used by Nielsen and Landauer (1993). They used it for usability problems, but it is also applicable for the number of answers found in interviews. This theory indicates that we found approximately 86% of the performance measures on the tactical level. We assume the measures not yet mentioned are the least important ones and therefore these five interviews are sufficient (Hannink, 2012; Klappe, 2012; Broers, 2012; Veraart, 2012; Elbrecht & Steenbergen, 2012).

<u>Utilization</u>

Utilization can be measured on multiple levels. The highest level is the total utilization for the whole hospital. In one of the interviews it was mentioned that the admissions planner should have more insights in the utilization on this higher level. An overview of the whole hospital might be too complex, but they should at least have insights in the wards that are preferred first and second by their specialism. Next to the utilization in total, also the utilization per ward is important. This utilization indicates whether a schedule is efficient. It would be useful if the tool gives the possibility to distinguish between day care and clinical patients for this measure. This could be necessary if a ward has separate beds per type of patients. A final level mentioned for utilization is the utilization for each specific bed. On all levels the utilization should be as large as possible.

Bed leveling

Next to increasing the average utilization also leveling this utilization over the days is mentioned multiple times during the interviews. The number of utilized beds could also be leveled during the day. This indicator was mentioned once during an interview.

Overutilization / Bed availability

Although the utilization is preferably as high as possible, there should not be too many patients in the hospital. The admissions planners should have insights in this on a hospital level and on a ward level. Not too many patients also means that there is always a bed available for an emergency patient. To reach this, beds should be reserved for those patients.

Staff availability

Previous mentioned performance measures are all about beds, but staff is also an important aspect. The planner should also know that enough staff of the right specialism is available.

Staff productivity

An indicator monitored for most wards is staff productivity. This is the number of patients on the ward per nurse. It is related to staff availability. The difference is that for enough staff to be available the number of patients per nurse should not be too high, while for productivity it should not be too low. An admissions planner can influence this by matching the number of patients on a ward to the number of nurses scheduled.

Patient satisfaction/Access time

During the interviews it is mentioned that the patient satisfaction is also important. If a schedule is optimal for the staff and for the hospital, this does not always mean that it will result in a high patient satisfaction. However, the wishes of patients differ a lot and it is not always possible to give the planner a clear overview of the forecasted patient satisfaction based on a schedule. Despite of this, performance for patients should still be an important indicator for the admissions planner. One specific performance indicator mentioned for patients is the access time. The access time is the time between the moment the patient knows he has to undergo a treatment and the moment he is actually admitted. The wards are not much involved in this performance measure. However, for the admissions planners it is important to have insights into this, because they can influence it with the schedule.

Amount of work

A final aspect is the amount of work. It was mentioned that the amount of work at the wards does not only consist of the patients present. Also the intensity of care of these patients and other tasks are important. This aspect was only mentioned once during the interviews at the tactical level. However, the interviewee expects that this will be too difficult to measure, so it would be best to focus on the number of beds first.

### 3.2.3 Measures on an operational offline/online level

The operational level of the wards consists of the staff of the wards, so the nurses and the managers of the wards. They are involved in both the operational offline and the operational online level. We explore their opinion about performance measures for the wards in two ways. We sent a survey to all managers of the wards. Next to that we interviewed a member of the VKI (Verpleegkundigen Kenniskring Isala) (van Apeldoorn, 2012); this is a works council for nurses in Isala Klinieken. A translation of the interview design is displayed in Appendix C and a translation of the questions from the survey is given in Appendix D.

<u>VKI</u>

The VKI is concerned with the interest of patients and nurses. They monitor whether agreements made in the hospital are met. The member of the VKI we interviewed is also manager of the Cardiology ward. According to her, multiple performance measures are important for the wards. These are partly based on the processes at Cardiology wards. The measures are the distribution of admissions over the day, the distribution of admissions over the week and the utilization of the wards. The admissions planners of Cardiology already consider these aspects by keeping track of the scheduled admissions and the resulting used beds themselves (Huenestein & de Graaf, 2012). An example of improving the distribution of admissions over the week is also allowing admissions during the weekend. The Cardiology wards are divided into multiple parts with different types of beds. These types are long stay patients, elective short stay patients and elective day care patients. The wards are judged based on utilization per type of bed and utilization of all Cardiology wards in total (van Apeldoorn, 2012).

<u>Managers of the wards</u>

The survey displayed in Appendix D was sent to all operational managers of 35 wards of Isala Klinieken. We received a response from managers of 32 wards.

In the beginning of the survey six performance measures are mentioned. The respondents are asked to indicate how important these aspects are for a good admissions schedule on a five point scale from not at all important to very important. The main goal of these questions is to make clear what the research is about. The subject of the research is relatively unknown for the staff at the wards. Therefore it is useful to give them some examples first. Figure 3.1 shows the results of these questions. It appears that all the performance measures are indicated by most people as important or very important. Therefore, we include all these aspects in the list of performance measures.

In the survey we also asked the respondents to mention more performance measures in multiple ways. We coded these performance measures ourselves, therefore it is subjective. This resulted in the categories given in Table 3.4.

In the survey we paid more attention to leveling the amount of work. This seemed an important aspect based on earlier conversations with staff at some wards. Also measuring this aspect might be complex. A question asked about this in the survey is whether the work should be leveled, whether a constant pattern in the work is enough or that both options are not necessary. This is asked for during the week and for during the day. The results are given in Table 3.2 and 3.3. From this we can see that a small majority prefers a constant pattern in the amount of work, as well for during the week as for during the day. However, also a large part of the respondents prefer the work to be leveled during the week and during the day. Therefore, we consider both leveled work and a constant pattern in the amount of work as performance measures for the ward.

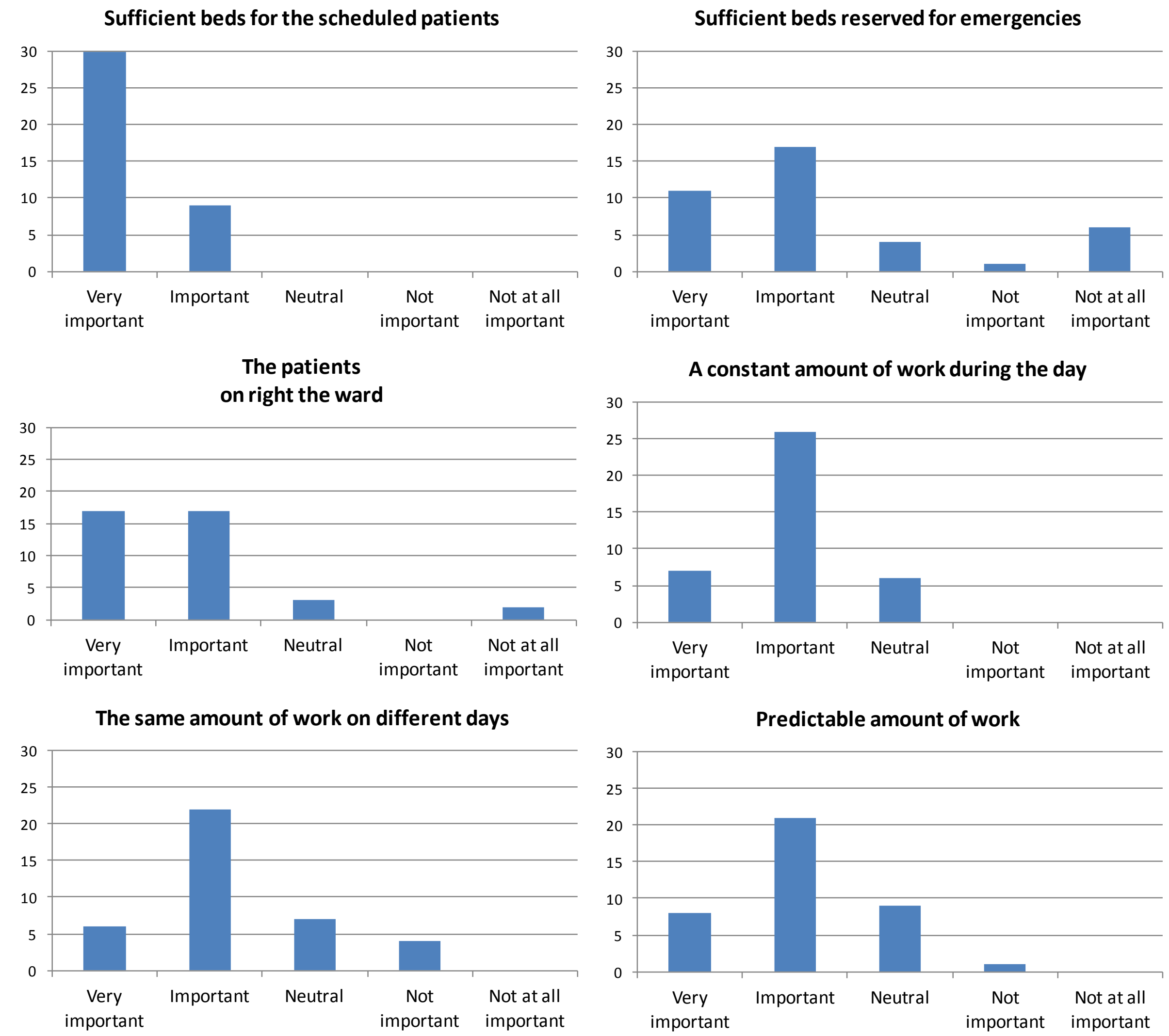


Figure 3.1 – Results for importance of aspects

Table 3.2 – Results of survey question about leveling the amount of work during the week

| Answer | Percentage |
|---|---|
| It would be ideal if the amount of work would be equal for all (week)days. | 32% |
| Amount of work does not have to be equal for all days, as long as there is constant pattern in the amount of work during the week (so on Monday always the same work as on other Mondays etc.) | 44% |
| Amount of work doesn't have to be equal for all days or according to constant pattern. | 24% |

Table 3.3 - Results of survey question about leveling the amount of work during the day

| Answer | Percentage |
|---|---|
| Amount of work should also be constant during the day. | 34% |
| Amount of work does not have to be constant during the day, as long as it follows a constant pattern (for example always a high amount of work between 10 and 11 am) | 39% |
| It is not necessary that the admissions planner tries to get the amount of work constant or according to a constant pattern during the day, this will go automatically. | 27% |

Table 3.4 - Performance measures from survey

| Performance measure | Number of times mentioned |
|---|---|
| Variability in number of admissions during the day | 14 |
| Overutilization per ward | 13 |
| Variability in number of admissions over the week | 9 |
| Admitting patients at the right time | 8 |
| Variability in amount of work during the day while considering other tasks at the wards | 6 |
| Overutilization on certain moments of the day | 6 |
| Staff availability | 6 |
| Patients on the right ward | 4 |
| Variability in number of used beds over the week | 4 |
| Utilization | 4 |
| Cancellations | 2 |
| Availability beds for emergency patients | 2 |
| Variability in amount of work over the week | 2 |
| Admissions in the evening | 1 |
| Predictable amount of work | 1 |
| Variability in amount of work during the year | 1 |
| Predictable number of admissions | 1 |

## 3.3 Overview performance measures

The previous two sections result in a long list of performance measures. To display this in a clear way we use the framework of Li and Benton (Li & Benton, 1996). For each quadrant of the framework we put the indicators in a KPI tree. In a KPI tree high level performance indicators (like for example costs) are divided into sub KPIs. In Isala Klinieken every department determined a number of key performance indicators (KPIs) on which they monitor the performance of their department. These KPIs are determined using a KPI tree. The goal of displaying it in this way is not to give an objective overview, just to give a clear overview of the indicators. Figures 3.2, 3.3 and 3.4 show these KPI trees. There were no external financial performance measures mentioned, so for that quadrant there is no KPI tree. The ends of the trees are performance measures we will further consider. In the next section we will reduce this long list of measures when evaluating them.

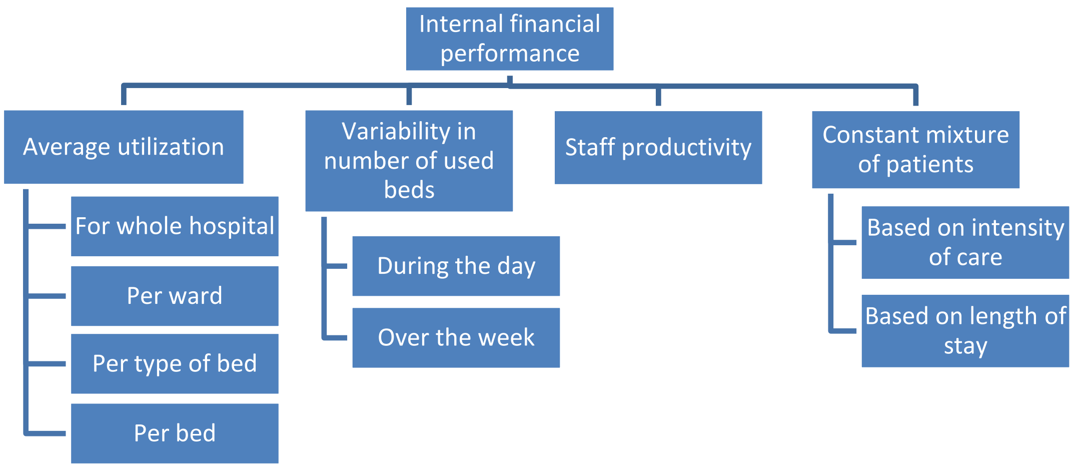


Figure 3.2 - KPI tree internal financial performance

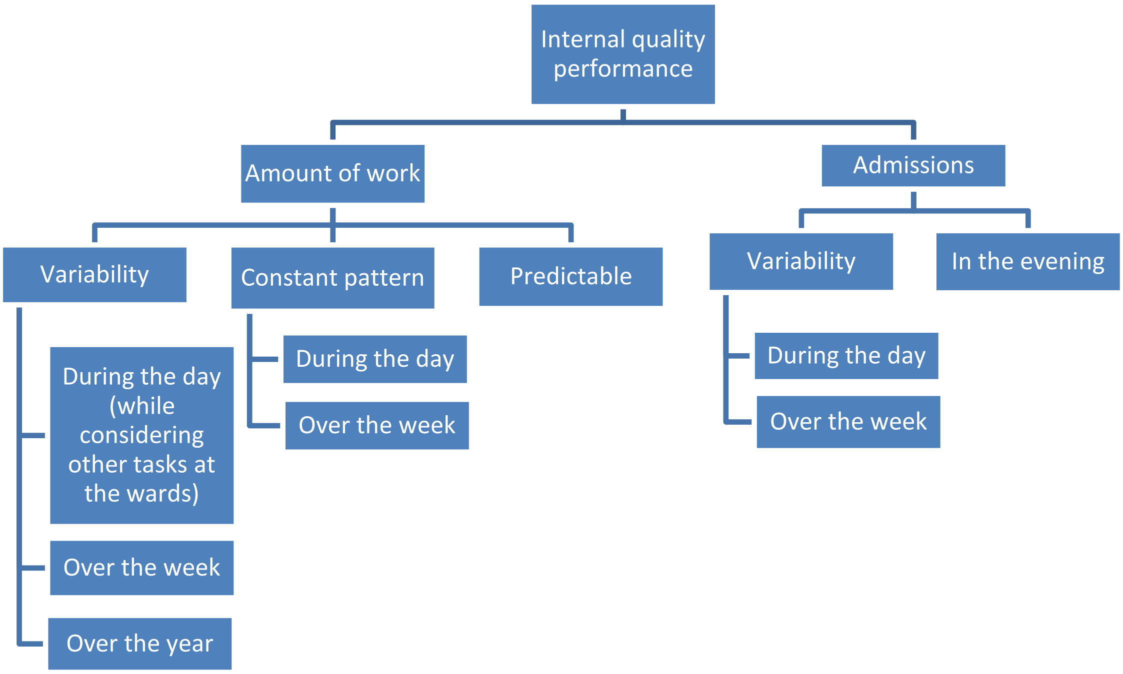


Figure 3.3 - KPI tree internal quality performance

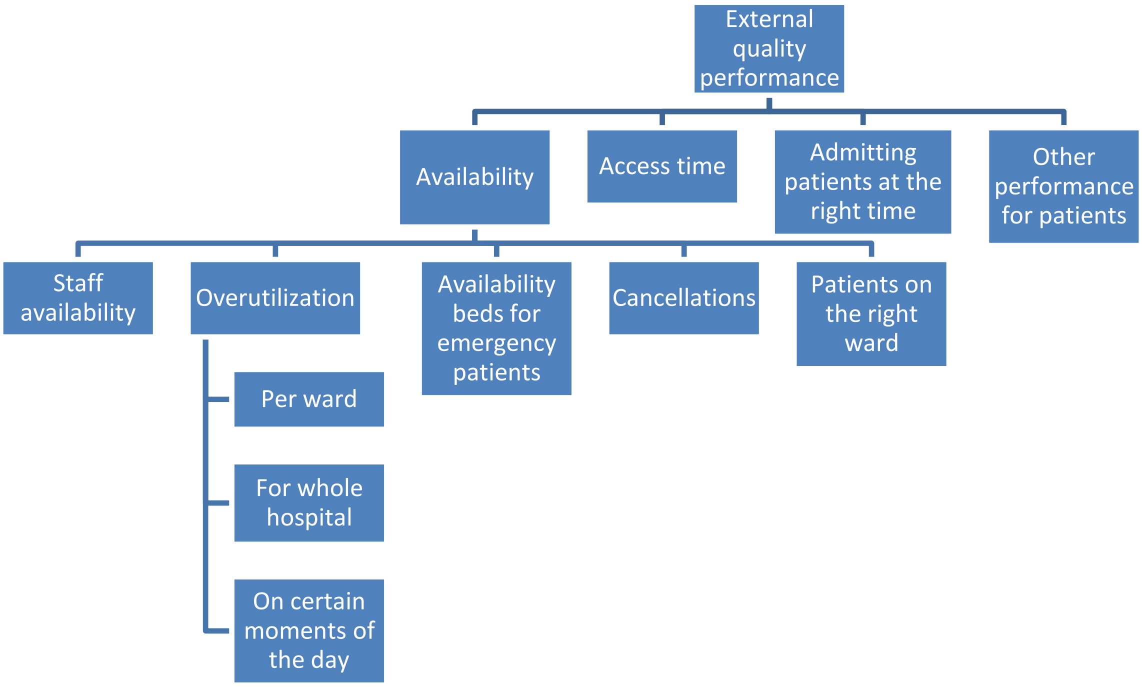


Figure 3.4 - KPI tree external quality performance

## 3.4 Evaluating performance measures

In this section we reduce the list of performance measures. The first step in this is to evaluate the measures based on the criteria mentioned in Section 3.1.2. If after this still too many measures remain, we determine which measures are most important according to the ranking from the interviews and the survey. So we first look at feasibility and then at importance.

The evaluation of the performance measures is subjective. To increase the objectivity of the evaluation we also let someone else evaluate the performance measures (van den Akker, 2012a).

Following, the level of agreement between the two evaluations can be calculated per evaluation criterion. The indicator used for the level of agreement is Cohen's kappa (Cohen, 1960). This indicator excludes the level of agreement that is expected by chance. Landis and Koch (1977) label the strength of agreement for different ranges of kappa. We use these labels to determine how strong the agreements for the different criteria are. If the level of agreement is substantial, almost perfect or perfect, we assume that our evaluation on that criterion is correct. If the strength of agreement is smaller, the indicators on which we do not agree are discussed. If even then the strength of agreement is not large enough, we ask a third person to evaluate the indicators on which there is no agreement.

An indicator should be included in the final list if it complies with all the criteria. Table 3.5 shows the values of Cohen's kappa before and after the discussion between the two evaluators. Before the discussion the values of Cohen's kappa are relatively small. The main reasons for this are the large number of performance measures and evaluation criteria and the relationships between the criteria, which make it difficult to evaluate in a constant manner. After the discussion there appears to be sufficient agreement for all indicators.

Table 3.6 shows the final evaluation of the indicators. The indicators that are selected in the total column comply with all the criteria. The other performance measures will not be considered further.

After this evaluation still seventeen performance measures remain. Showing all these measures to an admissions planner will be too complex to use. The tool must be simple to be effective. To do this, the list of performance measures needs to be further reduced. We rank the indicators per hierarchical level based on the answers on the interviews and the survey from Section 3.2. The strategic and tactical levels only consist of interviews. For these levels we look at how often the indicators are mentioned during these interviews. At the operational level we held one interview and we sent a survey to the wards. In the survey specific questions were asked about the amount of work. A majority preferred a constant pattern in the work during the week. This is logical, because with a constant pattern you can base your basic staff schedule on this pattern. Therefore we consider this indicator as ranked high enough to be included. For the work during the day also the majority prefers a constant pattern, but the difference with leveled amount of work during the day is very small. After discussing this with some employees of the wards we can conclude that leveling the work might be more useful, because it is difficult to change your staff schedule every moment of the day. For ranking the other aspects on the operational level we look at how often the aspects are mentioned in the survey and during the interview. All rankings are displayed in Table 3.7.

To reduce the list of indicators we only use the indicators that are ranked highest per hierarchical level. For the strategic level the tool will only use the indicator ranked first, because only one aspect was mentioned. For the tactical level the tool will show the first three indicators. The indicators ranked fourth were only mentioned once. Finally for the operational level we use the indicators ranked first to fifth. Figure 3.5 shows the final list of performance measures in a KPI tree.

**Table 3.5 - Cohen's kappas per criteria**

| Criteria | Cohen’s kappa before discussion | Cohen’s kappa after discussion |
|---|---|---|
| Specific/Transparent | 0,65 (substantial) | 1 (perfect) |
| Relevant | 0,10 (slight) | 0,91 (almost perfect) |
| Measurable | 0,37 (fair) | 1 (perfect) |
| Comparable | 0,02 (slight) | 1 (perfect) |
| Realistic/Can be influenced | 0,14 (fair) | 1 (perfect) |
| Time bounded | 0,28 (fair) | 1 (perfect) |
| Normative | -0,06 (poor) | 0,78 (substantial) |
| Total | 0,11 (slight) | 1 (perfect) |

**Table 3.6 - Evaluation of indicators**

| Performance measure | Specific/ Transparent | Relevant | Measurable | Comparable | Realistic/ Can be influenced | Time-bounded | Normative | Total |
|---|---|---|---|---|---|---|---|---|
| Utilization for whole hospital | X | | X | X | X | X | X | |
| Utilization per ward | X | X | X | X | X | X | X | X |
| Utilization per type of bed (for example emergencies, elective, day care etc.) | X | X | X | X | X | X | X | X |
| Utilization per bed | X | X | | X | | | | |
| Constant mixture of patients based on intensity of care | X | | X | X | X | X | X | |
| Constant mixture of patients based on length of stay | X | | X | X | X | X | X | |
| Variability in number of used beds over the week | X | X | X | X | X | X | X | X |
| Variability in number of used beds during the day | X | X | X | X | X | X | X | X |
| Overutilization per ward | X | X | X | X | X | X | X | X |
| Overutilization for whole hospital | X | | X | X | X | X | X | |
| Overutilization on certain moments of the day | X | X | X | X | X | X | X | X |
| Availability beds for emergency patients | X | | X | X | X | X | X | |
| Staff availability | X | X | X | X | X | X | X | X |
| Staff productivity | X | X | X | X | X | X | X | X |
| Patients on the right ward | X | X | X | X | X | X | X | X |
| Cancellations | X | X | | | X | | X | |
| Access time | X | | X | X | X | X | X | |
| Performance for patients | | | | | X | | | |
| Variability in number of admissions over the week | X | X | X | X | X | X | X | X |
| Variability in number of admissions during the day | X | X | X | X | X | X | X | X |
| Admitting patients at the right time | X | X | | | X | | | |
| Admissions in the evening | X | X | X | X | X | X | X | X |
| Variability in amount of work over the week | X | X | X | X | X | X | X | X |
| Variability in amount of work during the year | X | X | X | X | X | X | X | X |
| Variability in amount of work during the day while considering other tasks at the wards | X | X | X | X | X | X | X | X |
| A constant pattern in the amount of work during the day | X | X | X | X | X | X | X | X |
| A constant pattern in the amount of work over the week | X | X | X | X | X | X | X | X |
| Predictable amount of work | X | | | | | | | |

Table 3.7 - Ranking performance measures

| Performance measure | Ranking strategic level | Ranking tactical level | Ranking operational level |
|---|---|---|---|
| Utilization per ward | 1 | 1 | 7 |
| Utilization per type of bed (for example emergencies, elective, day care etc.) | - | 4 | 11 |
| Variability in number of used beds over the week | - | 1 | 8 |
| Variability in number of used beds during the day | - | 4 | - |
| Overutilization per ward | - | 4 | 2 |
| Overutilization on certain moments of the day | - | - | 4 |
| Staff availability | - | 4 | 4 |
| Staff productivity | - | 3 | - |
| Patients on the right ward | - | - | 8 |
| Variability in number of admissions over the week | - | 4 | 3 |
| Variability in number of admissions during the day | - | - | 1 |
| Admissions in the evening | - | - | 11 |
| Variability in amount of work over the week | - | - | 10 |
| Variability in amount of work during the year | - | - | 11 |
| Variability in amount of work during the day while considering other tasks at the wards | - | - | 4 |

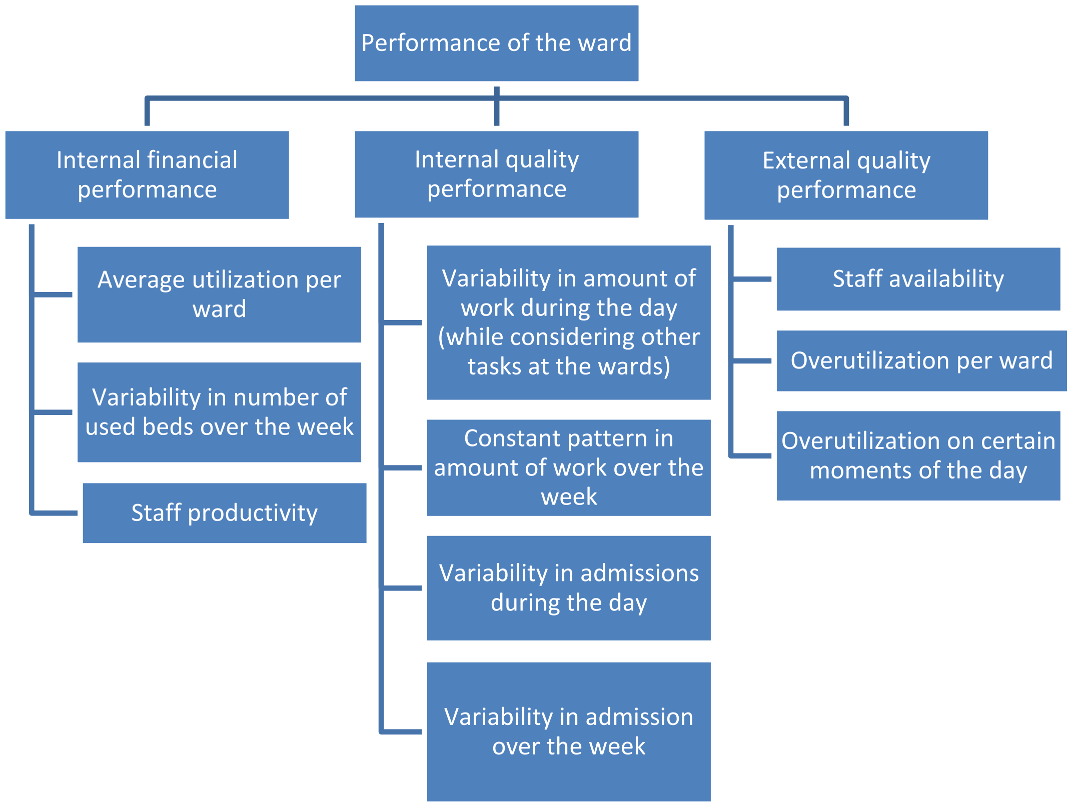


Figure 3.5 - KPI tree final list of performance measures

## 3.5 Measuring approach

After the evaluation in the previous section ten performance measures remain. The tool will show these performance measures. In the previous section it is already said that these indicators can be measured, but an exact way to calculate them should still be determined. This is necessary to calculate them in the tool, but also to determine the current performance in Section 3.6. Section 3.5.1 explains the way of measurement per indicator. For these calculations a lot of information is needed. Section 3.5.2 gives a list of this information.

### 3.5.1 Calculation of performance measures

Below we describe per performance measure the way in which it will be calculated. We base this on methods from literature and on the results of the interviews and the survey.

Utilization per ward

In Isala Klinieken multiple ways are used to measure the utilization (Hannink, 2012). The first way is the number of occupied beds at 10 am. 10 am is chosen because then most patients are not discharged yet, but there are already some new patients admitted. A second way of measuring utilization is the time the beds are occupied compared to the time the beds are available. Finally, utilization is also measured as the number of occupied beds at midnight compared to the total number of beds. This measure is especially used to say something about the scheduling on completely clinical wards. These wards only have patients that also stay during the night. If at such a ward a bed is used during two subsequent nights, it does not matter what happens in between, because you cannot schedule another clinical patient in it. Therefore, if at these wards all beds are used at midnight, the schedule was good regardless of what happened the rest of the day.

For the tool it is important to show the utilization in such a way that it gives a correct representation of the performance. Like just explained, for purely clinical wards it is sufficient to show the utilization at midnight. For purely day care wards the utilization during opening hours is important. The easiest way to calculate this is to compare the time the beds are occupied with the time they are available. Isala Klinieken has two wards that have both clinical and day care patients. For these wards both types of utilization are important.

The exact formulas for these types of utilization are:

$$\text{Utilization}_{0:00} = \frac{expected\ number\ of\ used\ beds(0{:}00)}{\#\ Beds\ available}$$

$$\text{Utilization}_{\text{opening hours}} = \frac{expected\ length\ of\ stay\ during\ this\ day * number\ of\ patients}{(\#\ Beds\ available) * (number\ of\ opening\ hours)}$$

The tool should show these numbers for all days in the scheduling horizon. The scheduling horizon is the period for which the schedule is complete and for which the admissions planner wants to know the quality for the wards. For the current performance in the next section we use the actual number of used beds and calculate the average utilization for the whole year.

Overutilization per ward/ Overutilization on certain moments of the day

Overutilization indicates how much the number of expected patients exceeds the number of beds available. In the list of performance measures two types of overutilization are mentioned. If a ward is completely occupied and on one day the same number of patients is discharged as admitted, this would not result in overutilization on the ward. However, because some patients might be admitted before others are discharged, it could give problems on certain moments of the day. Showing both measures in the tool might be confusing. Therefore we only show the overutilization on certain moments of the day.

The tool could show the expected number of patients that will not fit. However, there is much uncertainty about this number. A better way to represent the overutilization is giving the chance that there is overutilization.

To calculate this, the available number of beds and the distribution for the number of used beds are needed. The probability of overutilization can then be calculated for every hour of the day like shown in the formula below. The tool can show this in a graph.

Overutilization = $\sum_{number\ of\ patients > number\ of\ beds} P(number\ of\ patients)$

For the current performance and the realization we know with certainty whether there was overutilization. The probability of overutilization is either 0% or 100%. In Section 3.6, we therefore calculate the percentage of hours during a year on which there was overutilization compared to the opening hours (hours during which the utilization is larger than 0%). Some wards have extra beds which can be used in case of overutilization, for these wards we can recognize overutilization from the realization data. This is not the case for all wards, some wards transfer patients to other wards in case of overutilization, this influences the data about the current performance.

Variability in the number of used beds over the week

The variability in the number of used beds over the week should indicate how much the number per day differs from the average. There are different options to calculate variability. Table 3.8 lists the different options with some characteristics.

**Table 3.8 - Options to measure variability**

| Option | Formula | Characteristics |
|---|---|---|
| **Mean absolute deviation (MAD)** | $\frac{\sum\lvert x_i - \bar{x}\rvert}{n}$ | • Easy to understand (Gorard, 2005)<br>• Intuitive<br>• Efficient in the realistic situation (Gorard, 2005) |
| **Mean absolute percentage deviation (MAPD)** | $\frac{\frac{\sum\lvert x_i - \bar{x}\rvert}{n}}{\bar{x}}$ | • Easy to compare<br>• See characteristics MAD |
| **Variance** | $\sum(x_i - \bar{x})^2$ | • Quadratic unit<br>• Not intuitive |
| **Standard deviation** | $\sqrt{\sum(x_i - \bar{x})^2}$ | • Not intuitive<br>• Tradition (Gorard, 2005)<br>• Easy to manipulate algebraically (Gorard, 2005)<br>• Efficient under ideal circumstances (Gorard, 2005) |
| **Coefficient of variation** | $\frac{\sqrt{\sum(x_i - \bar{x})^2}}{\bar{x}}$ | • Easy to compare<br>• See characteristics standard deviation |

For the tool it is important that the planner understands what the indicators mean. From the options above the mean absolute deviation (MAD) is the most easy to understand. However, it is also important that the numbers are comparable. Weeks with a high average number of patients will often also have a larger MAD than weeks with fewer patients. To make sure it is comparable we use the mean absolute percentage deviation (MAPD) instead. This is also useful when you want to compare the results between departments.

To calculate the variability in the number of used beds we use the utilization like calculated before, because these numbers are already known. Using these numbers also makes it consistent with the other performance measures. The formula for this performance measure is shown below.

Variability used beds = $\dfrac{\frac{\sum_{days}|expected\ utilization - average\ utilization|}{number\ of\ days}}{average\ utilization}$

It is important to know for which days you determine the variability. If a ward is closed during the weekend it is clear that you do not take those days into account, but for other wards this is not clear. What is preferred differs between the hierarchical levels. Although this indicator was mentioned a few times by the operational level, it is included in the final list because of its importance for the tactical level. For the tactical level it is important because with a leveled number of used beds a higher utilization is possible. For this reason it is best to level the used beds over the whole week.

<u>Variability in number of admissions over the week</u>
This variability can be calculated in the same way as the variability in number of beds used, so displaying the MAPD. Only the expected number of admissions during the weekdays should be used for this, because no admissions are scheduled during the weekend.

Variability number of admissions over the week =

$$\frac{\frac{\sum_{days}|expected\ number\ of\ admissions - average\ number\ of\ admissions|}{number\ of\ days}}{average\ number\ of\ admissions}$$

<u>Variability in number of admissions during the day</u>

Because on many wards there are also hours without an admission, the variability in the number of admissions per hour does not give the right indication of the distribution of admissions over the day. Therefore it is better to calculate the variability in the time between admissions. This should then also be calculated as the MAPD.

Variability number of admissions during the day =

$$\frac{\frac{\sum_{admissions}|expected\ time\ between\ admissions - average\ time\ between\ admissions|}{number\ of\ admissions - 1}}{average\ time\ between\ admissions}$$

<u>A constant pattern in the amount of work over the week</u>
The first problem for this performance measure is how to determine the amount of work on a ward. During the survey for the wards questions were asked about this. According to 95% of the respondents the amount of work does not only depend on the number of beds occupied, but also on the intensity of care of the patients in those beds. Therefore we do take this into account.

In the intensity of care tool of Isala Klinieken also intensity of care of patients is used. To make both tools consistent and comparable, we use the same methods as in the intensity of care tool. In that tool nurses of the wards should indicate per reason for admission and per day, the intensity of care by giving them 1 to 4 care points. In the survey we checked whether it is necessary to differentiate the intensity of care per day or even per hour. 55% of the respondents prefers the intensity of care per day and 33% prefers it per hour. So it seems the right choice to let the nurses indicate it per day.

93% of the respondents of the survey state that not only the reason for admission is important to determine the intensity of care, but that also other patient characteristics should be considered. However, it is not clear which characteristics determine the intensity of care and how they should be combined to calculate it. Fasoli et al. (2011) give some indicators for intensity of care on a ward, like for example average length of stay and the number of patients that are 70 years or older. However, they do not say how to combine these indicators to determine one number for the intensity of care. Therefore it is not possible to include other patient characteristics. For some patients it might in advance be clear for the planner that the intensity of care differs from the standard, in that case it should be possible to change it.

In the survey also some other aspects are mentioned that cause work. Some of these aspects cannot be included because they are difficult to predict. The other aspects consist of patient specific and ward specific tasks. The patient specific tasks are the admissions (95% of the respondents) and the discharges (85%). These tasks should be predicted by the tool and care points should be allocated to them. The intensity of care tool also considers admissions and discharges. An example of a ward specific task is the visits of the specialists. This does often not differ per day. Therefore we do not consider this here.

The amount of work can be calculated using the following formula:

Amount of work per day = $A * \sum_{h=0}^{23} x_A(h) + D * \sum_{h=0}^{23} x_D(h) + 24 \sum \left(I_{L,R} * x_{L,R}\right)$

In this formula the variables mean:

| | |
|---|---|
| $A$ | care points per admission |
| $x_A(h)$ | number of admissions during hour h |
| $D$ | care points per discharge |
| $x_D(h)$ | number of discharges during hour h |
| $I_{L,R}$ | care points per patient already L days in the hospital and with admission reason R |
| $x_{L,R}$ | number of patients at the ward that are already L days in the hospital and have admissions reason R |

The intensity of care for patients is multiplied by 24 because these care points are based on the care needed per patient during one hour. For the number of patients we again use the patients at midnight or the average between opening hours, depending on the type of ward.

From this work per day the tool should determine whether there is a constant pattern over the week. We use the seasonality index for this. The seasonality index is the work on a certain day divided by the average work over the week. The mean absolute deviation from a standard index per weekday indicates whether it follows the constant pattern. The formula for this is displayed below. By comparing the seasonality index instead of the actual work, this performance measure does not depend on the total work during the week. The standard seasonality index per weekday should be determined in advance. This could be based on historical data or on preference of the wards.

Deviation from constant pattern in amount of work over the week =

$$\frac{\sum_{days}\left|\frac{expected\ amount\ of\ work}{average\ amount\ of\ work}-standard\ seasonality\ index\right|}{number\ of\ days}$$

Variability in the amount of work during the day while considering other tasks at the wards

For this performance measure also the amount of work is needed. For this the same approach is used as for the previous measure. The difference is that now the work should be determined per hour. The ward specific tasks should now be taking into consideration. We will include this by changing the number of care points that one nurse can accomplish during an hour. The formula for the amount of work for this indicator than becomes:

Amount of work per hour(h) = $\frac{A*x_A(h)+D*x_D(h)+\sum(I_{L,R}*x_{L,R})}{care\ points\ per\ nurse\ during\ this\ hour}$

The work has to be constant over the day. For this we use the MAPD, just like for the other indicators about variability. 86% of the respondents states that it is not necessary for the work to be stable 24 hours per day, it is sufficient if it is constant during the day (opening hours). The admissions planner can only influence the variability during the day, so we measure the variability during these hours.

Variability amount of work during opening hours = $\frac{\frac{\sum_{hours}|expected\ amount\ of\ work(h)-average\ amount\ of\ work|}{number\ of\ hours}}{average\ amount\ of\ work}$

Staff availability/productivity

The performance measures staff availability and productivity partly overlap. Staff availability means that on days that fewer personnel are scheduled also fewer patients should be scheduled. This actually means keeping the productivity constant.

Staff productivity is the average number of patients per nurse. For the staff availability especially the number of nurses during the day is important, this is the number that changes the most between days. Therefore we calculate per day an average productivity during the opening hours. Isala Klinieken does not yet have a staff scheduling system, so it is not possible to easily determine the number of staff per shift. However, wards do have a basic staff schedule. This schedule can be used to determine the expected productivity per shift.

To determine whether the staff productivity is constant, again we use the MAPD. Next to that the productivity should be high enough such that it meets a certain norm. Therefore the average productivity is also important.

Staff productivity = $\frac{Average\ number\ of\ patients\ during\ opening\ hours}{Average\ number\ of\ nurses}$

Staff availability (variability in productivity) = $\frac{\frac{\sum_{days}|expected\ productivity-average\ productivity|}{number\ of\ days}}{average\ productivity}$

### 3.5.2 List of required information

For the calculations described above a lot of information is required. Some of this information should be determined by the wards, the planners or the management of a specialism. Other aspects should be forecasted based on the schedule. Table 3.9 gives a list of settings needed and Table 3.10 describes the data that should be predicted by a model.

**Table 3.9 - Settings**

| Setting | Needed for |
|---|---|
| Type of ward (purely day care, purely clinical or combination) | Utilization<br>Variability number of used beds over the week |
| Opening hours | Utilization<br>Variability number of used beds over the week<br>Variability amount of work over the day |
| Number of beds available | Utilization<br>Overutilization |
| Length of stay per treatment type | Utilization |
| Standard seasonality indices for amount of work per day | Constant pattern in amount of work over the week |
| Intensity of care per reason of admission and per day | Constant pattern in amount of work over the week<br>Variability amount of work over the day |
| Changes in intensity of care for specific patients | Constant pattern in amount of work over the week<br>Variability amount of work over the day |
| Care points per admission | Constant pattern in amount of work over the week<br>Variability amount of work over the day |
| Care points per discharge | Constant pattern in amount of work over the week<br>Variability amount of work over the day |
| Number of care points possible per nurse for each hour of the day | Variability amount of work over the day |
| Basic staff schedule per hour and per day of the week | Staff availability/productivity |

**Table 3.10 - Forecasts**

| Forecast | Needed for |
|---|---|
| Expected number of used beds per hour | Utilization<br>Variability number of used beds over the week |
| Distribution of the number of used beds per hour | Overutilization |
| Expected number of admissions per day | Variability number of admissions over the week<br>Constant pattern in amount of work over the week |
| Expected times between scheduled admissions | Variability number of admissions during the day |
| Expected number of discharges per day | Constant pattern in amount of work over the week |
| Expected number of patients per hour, for each reason of admission and for each number of days already in the hospital | Constant pattern in amount of work over the week<br>Variability amount of work over the day |
| Expected number of admissions per hour | Variability amount of work over the day |
| Expected number of discharges per hour | Variability amount of work over the day |

## 3.6 Current performance

Section 3.4 gives a list of performance measures which the admissions planners should see about the wards. We want to know what the current performance is based on these measures. The different subsections describe this current performance per indicator.

### 3.6.1 Utilization per ward

Most wards of Isala Klinieken are clinical wards. For these wards the utilization at midnight is important. This is displayed in Figure 3.6 and 3.7. The wards are divided into general wards and intensive/specific wards. For the day care wards the utilization during the day is relevant. Figure 3.8 shows for these wards the average utilization between 7 am and 6 pm. Wards A2 and A2K on location Weezenlanden are clinical wards, but they are also meant for day care patients. Therefore for these wards both types of utilization are important.

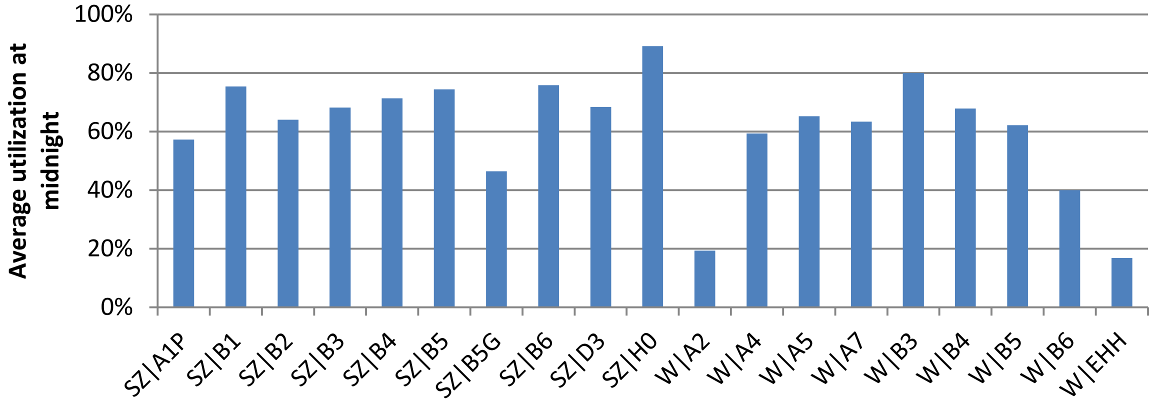


Figure 3.6 - Utilization at midnight general wards (iZis, 2011, n = 45083 patients)

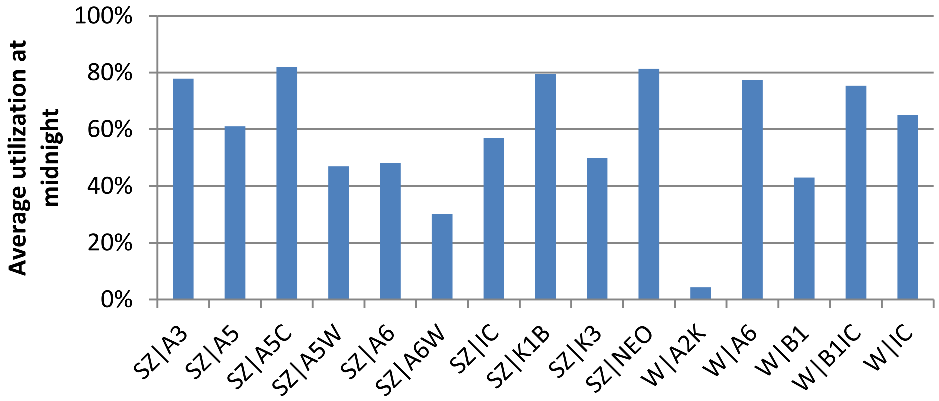


Figure 3.7 - Utilization at midnight intensive and specific wards (iZis, 2011, n = 15033 patients)

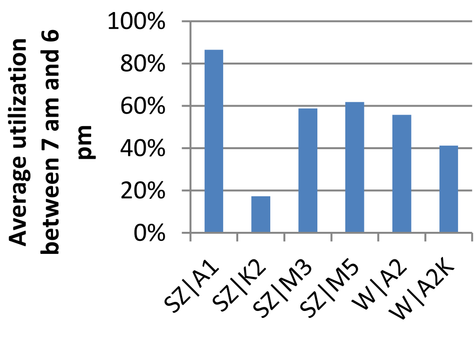


Figure 3.8 - Utilization during opening hours (iZis, 2011, n = 32245 patients)

As can be seen in the graphs the utilization differs a lot per ward. What stands out is the small utilization at midnight at wards W|A2 and W|A2K. These wards are meant for short stay patients and are therefore also open during the night, but apparently only a few beds are used then. Also the utilization on wards SZ|K2 and W|EHH is low compared to the other wards. The reason for the low utilization at W|EHH is that it is an emergency ward for Cardiology and Lung medicine.

### 3.6.2 Overutilization per ward/ Overutilization on certain moments of the day

The current performance for overutilization is the number of hours on which there is overutilization compared to the number of hours on which the utilization is larger than zero. This is comparable to the probability of overutilization on a ward, which will be used in the tool. Figure 3.9 and 3.10 show the performance for clinical wards and Figure 3.11 for day care wards.

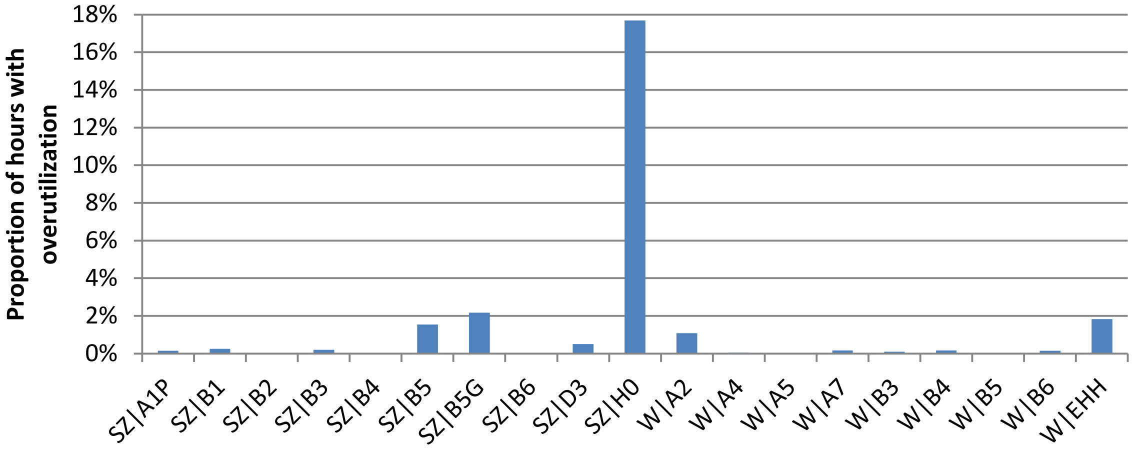


Figure 3.9 - Overutilization general wards (iZis, 2011, n = 45083 patients)

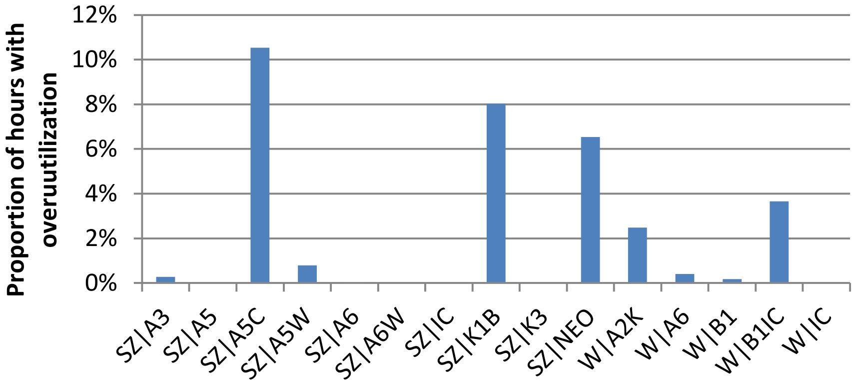


Figure 3.10 - Overutilization intensive and specific wards (iZis, 2011, n = 15033 patients)

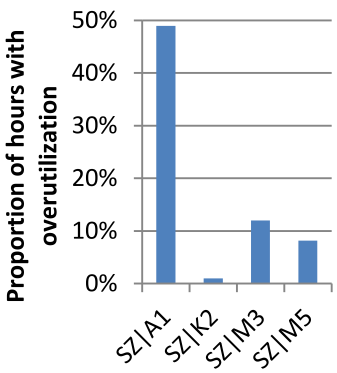


Figure 3.11 - Overutilization day care wards (iZis, 2011, n = 20062 patients)

For general wards the proportion of hours with overutilization is relatively small, with one exception, ward H0 on location Sophia. This is the ward for psychiatry patients. The reason for this is not known. For intensive and specific wards the performance differs, but there are no extreme outliers.

For day care wards the proportion of hours with overutilization is relatively large, except for ward K2 on location Sophia. For K2 this corresponds to the small utilization. When average utilization is low it is unlikely that the proportion of hours with overutilization is large. The large probability of overutilization on the other day care wards is also explainable. It is possible for most day care patients to stay in a chair instead of a bed at the end of their admission period. These chairs are not considered in the calculations.

In advance we expected that wards with a large average utilization also have a large proportion of hours with overutilization. For intensive and day care wards this pattern is visible in the graphs. However, for general wards this is not the case, this probably has to do with the variability in the number of beds. The next section describes this aspect.

One of the expected reasons for overutilization on certain moments of the day is the fact that some new patients are already admitted while others have not yet been discharged. Figure 3.12 proves this idea: the peak of admissions happens before the peak of discharges. This results in a peak in the number of used beds in the morning (Figure 3.13).

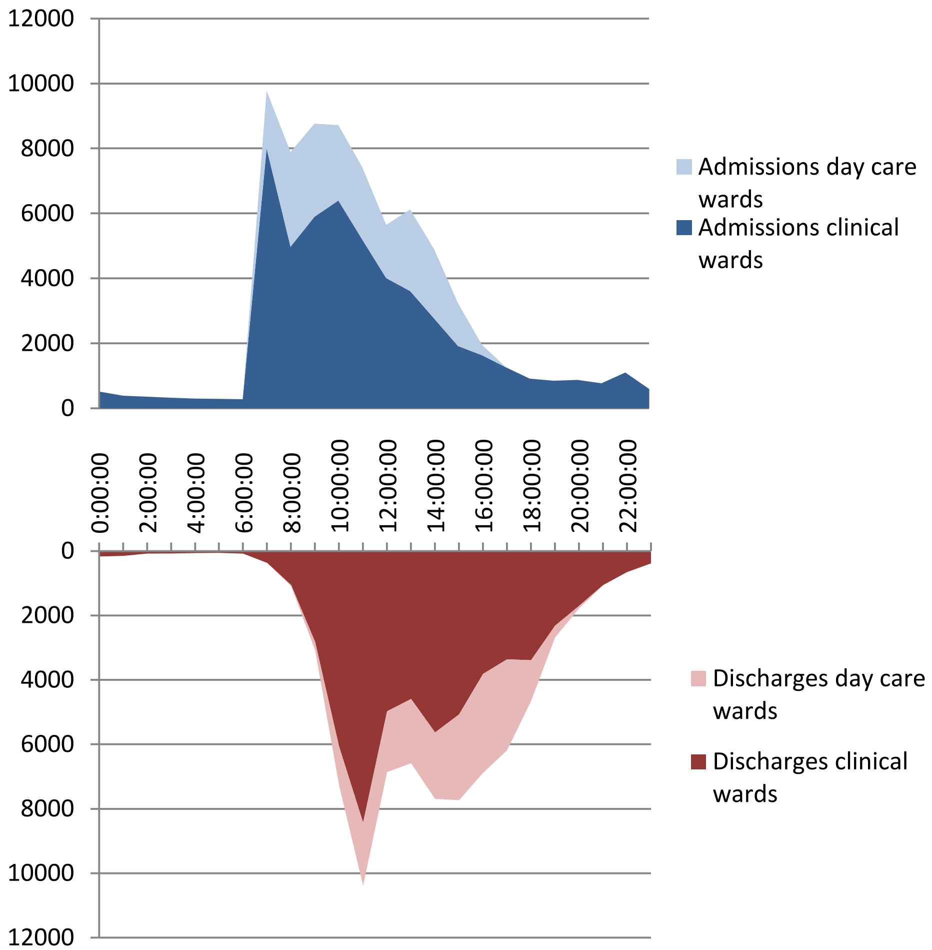


**Figure 3.12 - Average number of admissions and discharges per hour (source: iZis, 2011, n = 80178 patients)**

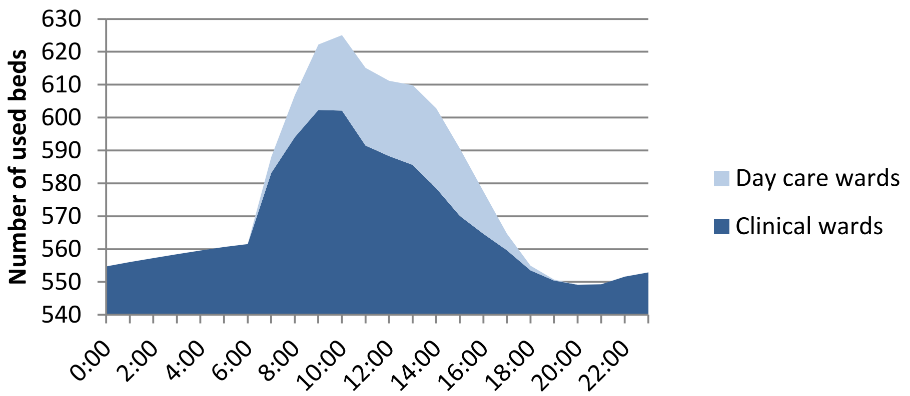


Figure 3.13 - Average number of beds per hour (source: iZis, 2011, n = 80178 patients)

### 3.6.3 Variability in number of used beds over the week

Figure 3.14, 3.15 and 3.16 show the variability in the number of used beds over the days. It appears that wards with a very small average utilization, often have a large variability in that utilization, like for example W|A2K, W|EHH and SZ|K2. This is logical, because when a large variability is a given, the only way to deal with this without creating too much overutilization is keeping the average utilization low. The graphs also show that day care wards have a relatively large variability in the number of used beds during the week.

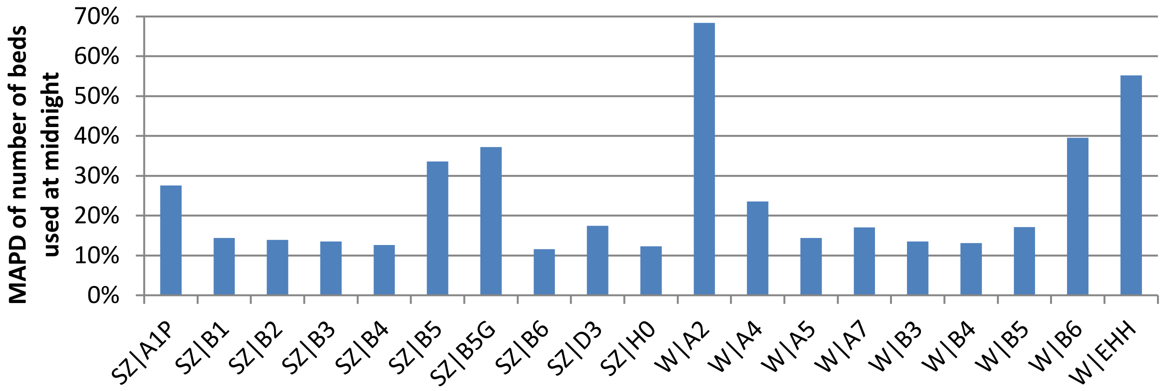


Figure 3.14 – Variability in the number of used beds at midnight general wards (iZis, 2011, n =45083 patients)

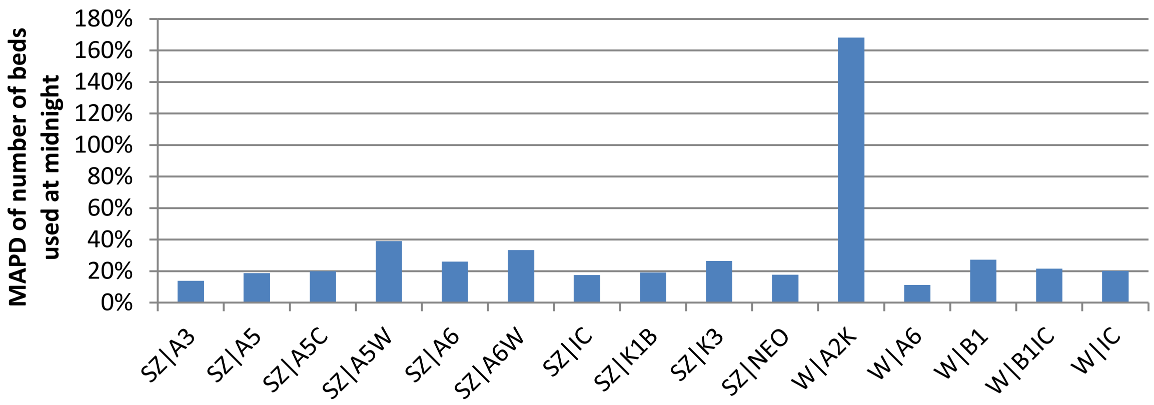


Figure 3.15 – Variability in the number of used beds at midnight intensive and specific wards (iZis, 2011, n = 15033 patients)

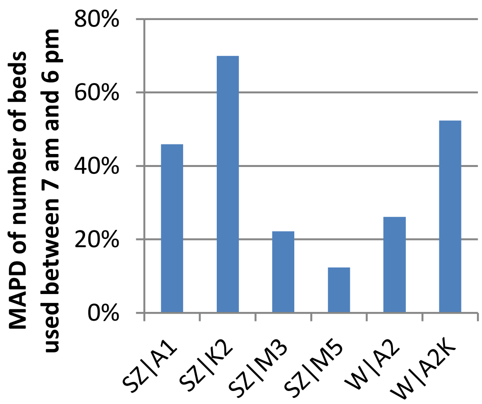


Figure 3.16 – Variability in the number of used beds during opening hours (iZis, 2011, n = 32245 patients)

In the previous section for some wards the probability of overutilization could not be explained by a large utilization, like for example SZ|B5G and W|EHH. Now it appears that these wards have a relatively large variability in the number of used beds. So we can conclude that causes of overutilization are a high average utilization and a large variability in that utilization.

The variability is determined by calculating the deviation from the average utilization over a whole year. However, this deviation is not random; there is a pattern during the week (Figure 3.17). In the weekend fewer beds are occupied, but also during weekdays the number of used beds is not constant.

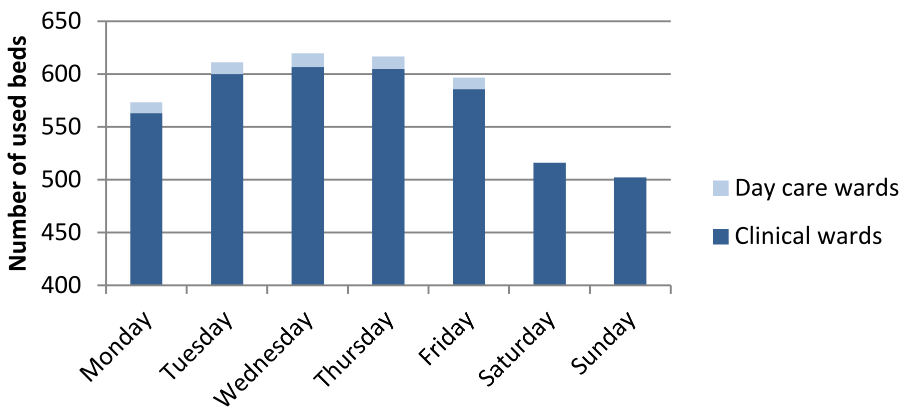


Figure 3.17 - Average number of beds per weekday (source: iZis, 2011, n = 80178 patients)

### 3.6.4 Variability in number of admissions over the week

The next indicator is the variability in the number of admissions over the week. Figure 3.18, 3.19 and 3.20 show the current performance of this indicator. When you compare Figure 3.16 with Figure 3.20 it becomes clear that for day care wards there is the same pattern in the variability in the number of beds as in the admissions. This is logical because patients on these wards leave before the end of the day, so the number of used beds is (almost) equal to the number of admissions.

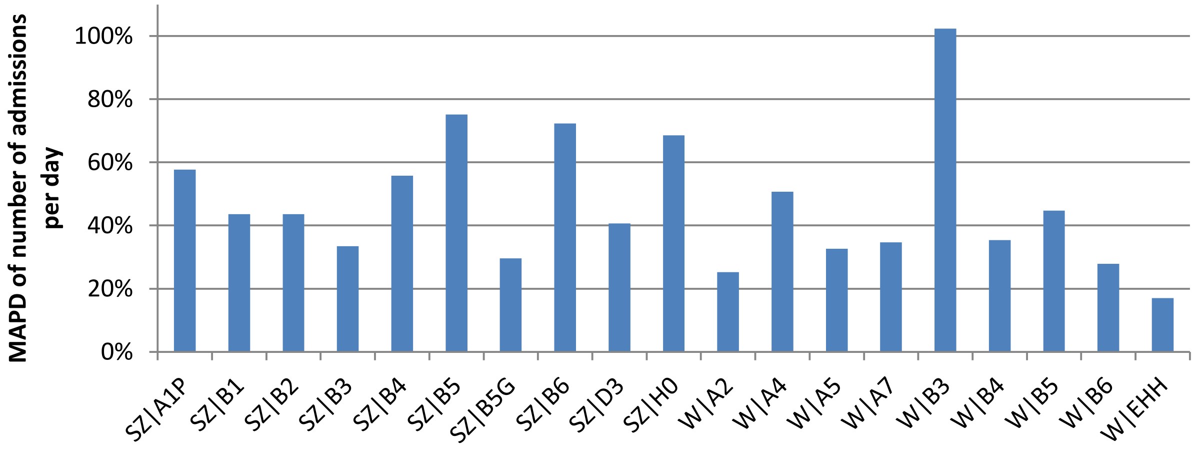


Figure 3.18 – Variability in the number of admissions over the week general wards (iZis, 2011, n = 45083 patients)

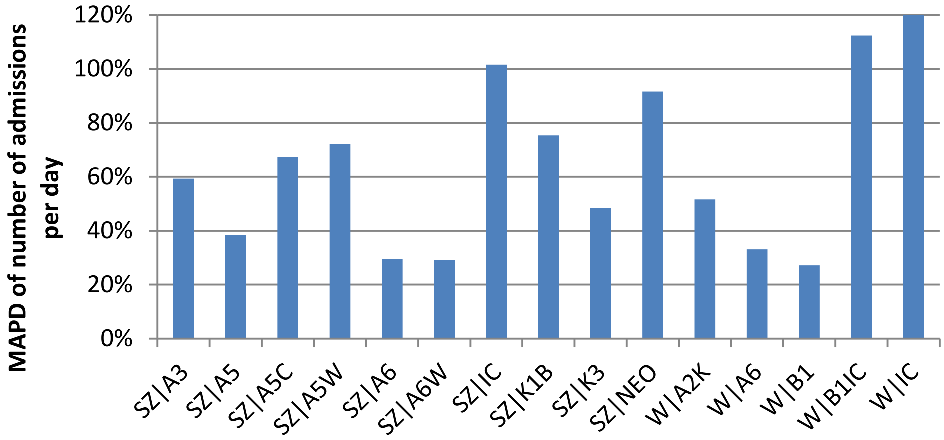


Figure 3.19 – Variability in the number of admissions over the week intensive and specific wards (iZis, 2011, n = 15033 patients)

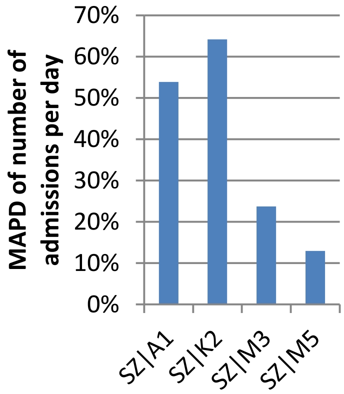


Figure 3.20 – Variability in the number of admissions over the week day care wards (iZis, 2011, n = 20062 patients)

Another aspect that stands out is the high variability for the intensive care units. A probable reason for this is that these wards are scheduled by planners of multiple specialisms. If a ward is scheduled by one planner, it is easier to already consider the number of admissions for the ward. For the ICs there is no control for this at all. Also ward B3 on location Weezenlanden is an outlier, the reason for this is not known.

### 3.6.5 Variability in number of admissions during the day

For the variability in the number of admissions during the day, we only considered days with more than one admission. On days with one admission it is not possible to distribute the admissions better. Figures 3.21, 3.22 and 3.23 show the results. The variability is especially large for the day care and short stay wards, W|A2 and W|A2K. However, there are no extreme outliers.

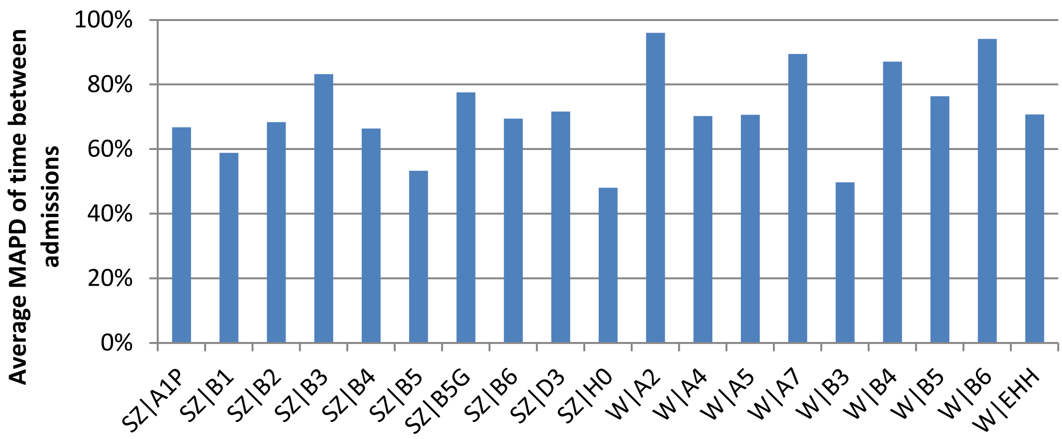


**Figure 3.21 – Variability in the number of admissions during the day general wards (iZis, 2011, n = 45083 patients)**

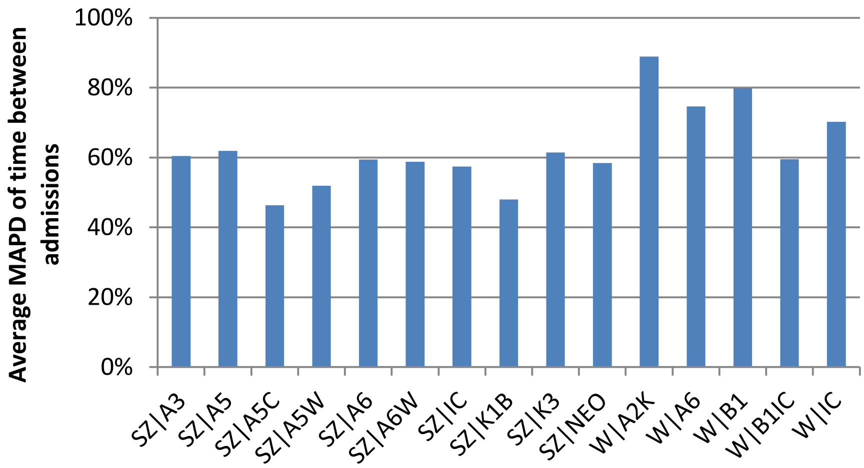


**Figure 3.22 – Variability in the number of admissions during the day intensive and specific wards (iZis, 2011, n = 15033 patients)**

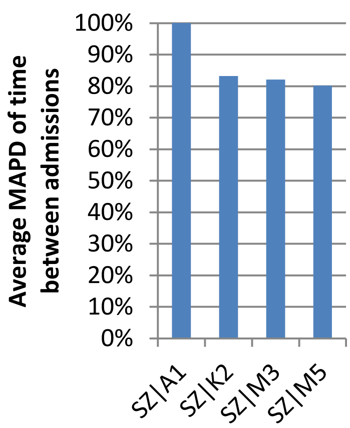


**Figure 3.23 – Variability in the number of admissions during the day day care wards (iZis, 2011, n = 20062 patients)**

The reason that this indicator was mentioned by managers of the wards is that often a lot of admissions are scheduled at the same time. Figure 3.12 already shows that especially between 7 and 8 am a lot of patients arrive.

### 3.6.6 A constant pattern in the amount of work over the week

To calculate the amount of work for a ward we need information about intensity of care per type of treatment and we need the care points for admissions and discharges. These numbers should be determined by staff of the wards. For most wards these numbers are not yet available. However, the same numbers are also used in the intensity of care tool. Two wards already use this tool, so for these wards it is possible to calculate the current performance of this indicator. These wards are SZ|B5G and the Urology part of W|A5.

As the standard seasonality indices we choose the averages per day of the week over the whole year. Figure 3.24 shows these indices for both wards. The mean absolute deviation from the standard seasonality index for Urology at W|A5 is 0,114. The MAPD is the same, because the average seasonality is 1. This is not extremely large, but the amount of work also does not exactly follow a constant pattern. For SZ|B5G the MAPD is even larger, namely 0,215. So this ward follows even less a constant pattern.

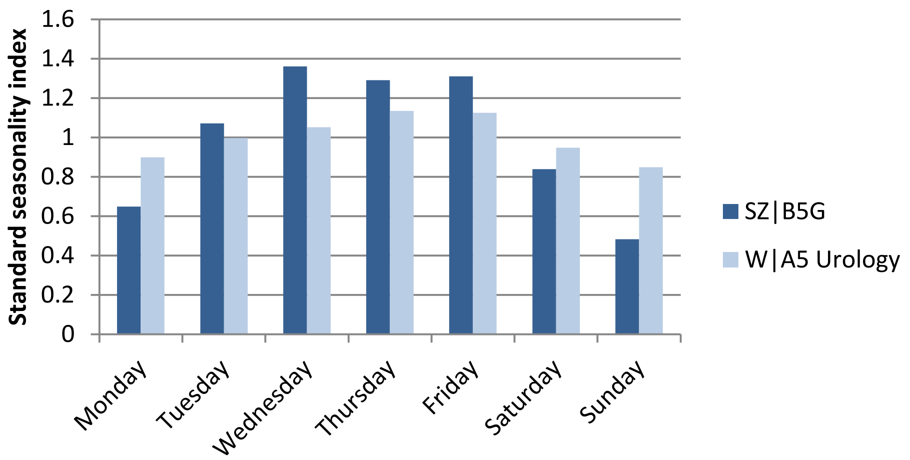


Figure 3.24 - Standard seasonality indices amount of work (iZis, 2011, n = 2771 patients)

### 3.6.7 Variability in amount of work during the day while considering other tasks at the wards

For ward SZ|B5G the average MAPD in the amount of work during the day is 51,2%. This is very high. It means that the work is not evenly distributed over the day. For Urology on ward W|A5 the MAPD is 23,5%, so on that ward the work is better distributed over the day.

### 3.6.8 Staff availability/Productivity

Because Isala Klinieken does not have a staff scheduling program, it is not possible to calculate the staff availability and productivity for all wards. However, the intensity of care tool uses the basic staff schedule. So for the wards that use this tool we can calculate the current performance for this indicator.

For Urology on W|A5 the average staff productivity during opening hours in 2011 was 4,18 patients per nurse. The mean absolute percentage deviation in this productivity is 21,4%. So the staff productivity is large, but there is also a large variability in this productivity.

Ward SZ|B5G, Gynecology has an average staff productivity of 2,94 patients per nurse. This is much smaller than the productivity of Urology, but it is difficult to compare these numbers, because it highly depends on the complexity of patients at a ward. The mean absolute percentage deviation of the productivity at SZ|B5G is 25,9%. This is just a little bit larger than the variability at the Urology ward.

This chapter described the performance measures that should be included in the tool. The list, which is determined based on literature and interviews and a survey within the hospital, is displayed in Figure 3.5. This chapter also discussed a way to measure these performance indicators and the current performance based on these measures. From the current performance, it becomes clear that improvements might be helpful. The tool developed in this study can contribute to this. For the tool to be effective the way of presenting the performance measures is very important. The next chapter will focus on that aspect.

# Chapter 4 – Tool expectations

From the previous chapter we know which performance measures are important for the wards. The next question is how these measures should be presented in a tool. The admissions planners are important in this, because they will use the tool. However, also the department Patient Logistics is involved, because they initiated the research. Section 4.1 discusses the opinion of this department. The opinion of the admissions planners is discussed in Section 4.2. Finally in Section 4.3 all these aspects are combined in a conceptual model for the tool.

## 4.1 Department Patient Logistics

The department Patient Logistics consists of one employee, Bernd van den Akker. During an interview with him we discussed multiple aspects about the tool. Appendix E gives a translation of the design of the interviews with the admissions planners, during the interview with Bernd van den Akker the same design was used; only the first eight questions were skipped.

Interaction with current scheduling process

The current scheduling program focuses on a perspective per patient. The tool should complement this with a ward perspective. It should give an overview instead of looking at individual patients. It would be ideal if the tool could generate an optimal schedule and the admissions planner only has to check whether the schedule is feasible. However, it is not possible for a computer to generate an optimal schedule because of many constraints. Therefore, it is better if the tool shows the quality of a schedule when the schedule is ready and before the patients are notified about the admissions. The moment that a schedule is ready differs per department. This depends on the scheduling horizon (van den Akker, 2012b).

The tool should be integrated with the current scheduling program. However, this will not be possible immediately. First it should be proven that it works outside the program (van den Akker, 2012b).

Until now we assumed the main goal of the tool should be to give the admissions planner insights about the current schedule. However, during the interview it was mentioned that it should also be possible to use previous schedules as input. In this way it is possible to see whether there is a trend in the quality of scheduling. Then you can also compare the expected quality to the realized quality, which indicates what influence the schedule has on the realization (van den Akker, 2012b).

Layout

The next aspect discussed during the interview is the layout of the tool. According to Bernd van den Akker (2012b) the tool should show two tabs, namely results and settings. The settings tab should for example show the wards for which the planner schedules, the weighting factors, the scheduling horizon etc. The results should be displayed in different layers. The highest layer is the total quality grade. The layer below is a grade per performance measure, because with only one total grade the planner does not know how to improve it. Per performance measure there should also be a graph over time with norms. For the quality grades there should also be a norm. The norms will differ per specialism and the grades cannot be compared between specialisms, because the complexity of scheduling differs a lot (van den Akker, 2012b).

Some planners schedule for multiple wards, if these wards have a combined staff schedule the tool should combine the performance measures for these wards. If this is not the case separate graphs and sub grades should be given for the wards (van den Akker, 2012b).

Next to these layers the results tab should show the trend of previous quality grades and the trend in difference between expected quality and realization. This last aspect does not help to schedule better, but it does help the planner to trust the tool (van den Akker, 2012b).

<u>Interaction between specialisms</u>
Some wards are used by multiple specialisms and scheduling for these wards is therefore done by multiple planners. In the new hospital this will happen even more. According to Bernd van den Akker (2012b) scheduling these wards should be done by one admissions planner or by multiple planners that make the schedule together. Therefore, we do not have to take this into account for the tool. Extreme examples of wards that are used by multiple specialisms are day care and short stay wards. Also for these wards it would be best if the planners work together to make the schedule (van den Akker, 2012b).

<u>Other aspects</u>
Finally it was mentioned that the tool should be easy to understand, it should not cost much time to use and it should be very flexible regarding the input needed for the calculations (van den Akker, 2012b).

## 4.2 Admissions planners

In Isala Klinieken a lot of people are involved in scheduling admissions. The surgical specialisms often have a planner or a planning team that schedules the admissions. For most non-surgical specialisms the admissions are scheduled by the secretaries of the policlinic, because for these patients the admissions should often take place within a few days. Finally, for some day care wards the admissions are scheduled by a secretary of the ward. To get a complete overview of what admissions planners expect of the tool, we approached planners from all these different areas for an interview. We interviewed the planners from Internal Medicine, Urology, Orthopedics, Gynecology, Cardiology and General Surgery (Smulders, 2012; Boerendans & Vos, 2012; Oosterveld, 2012; van den Berg, 2012; Schutte, 2012; Huenestein & de Graaf, 2012; Vogelzang, 2012). Appendix E gives a translation of the interview design for these interviews.

<u>General idea about the research</u>
During the interviews it became clear that it will not be possible for all the specialisms to use the tool in the same way. It will differ per specialism for which purposes the tool will be used. The main purposes recognized during the interviews are:

- *Making improvements to a future schedule*
  This is only possible if the schedule is made far enough in advance and if the appointments are not yet announced to the patients. For this purpose, forecasts are needed for the patients that are not yet scheduled, like for example the emergency patients.
- *Check afterwards*
  For the specialisms that do not schedule far enough in advance, the tool can be used to indicate improvements for the next period and for monitoring by management. For this it is

necessary that the tool also works for a complete schedule, the results should be visible for management and it should be possible to compare the results with previous periods.

- *Demonstrating to management what the problems are*
  Some admissions planners are not able to change much about the effects for the wards, often because they are bounded by decisions on a higher level, like for example the OR block schedule or the division of specialists over the blocks. The tool could help the planners to demonstrate these problems, instead of just basing it on a feeling. Using these expectations from the tool will result in less noise than using the realization on the ward. To demonstrate what the problem is, it is necessary that the tool gives specific and clear numbers per indicator.

During the interview with the planners of a day care ward it became clear that they now use another scheduling program than other planners. However, it is not necessary to focus on this, because it is the intention that all planners will use the same scheduling program in the future.

Interaction with current scheduling process

The next subject discussed during the interviews is the interaction with the current scheduling process. One aspect that is mentioned often is that it should be linked to the current scheduling program, iZis. How it should be linked is not clear. It could be completely integrated, but a button that opens the tool is also sufficient. At least it should use actual data from the scheduling program.

The planners prefer to use the tool when one patient is scheduled. However, for this already a lot is possible in the current scheduling program. This information is often not used, but it is available. Therefore, we focus on a tool that is used after a first version of the schedule is available. This is recognized by most of the planners. They mention that the scheduling period for which the tool can be used should not be too short, because than it is difficult to get an overview and to make changes.

A final aspect mentioned is that the planners should be able to use the tool far enough ahead. This is useful for the wards, but it is also the only way in which you still can change something in the appointments with patients.

Layout

The main aspect mentioned about the layout of the tool is that it should not become too complex. The ideas about how to keep it simple differ. Examples are using colors and showing graphs.

All planners prefer separate graphs or numbers per performance measure and per ward. Most of them want to see a norm for the performance measures, but only if this norm is not fixed in advance. Not all planners agree to this. Displaying a norm gives the feeling that you have to achieve something and that you are judged.

The tool should also show the trend of the performance, such that improvements become visible and you can learn from it. With these trends it can also be used as management information.

Interaction between specialisms

In the current situation some specialisms share the same ward. How the planners deal with this differs a lot. For some wards agreements are made about the number of beds per specialism. If one specialism exceeds this number it should be discussed with a central planner. Other wards have completely separate beds and staff for each specialism. A final solution is to just schedule separately and check right before the schedule is executed if it fits.

All these ways of working are not seen as an ideal situation. Solutions mentioned are a central scheduling office that still has some decentralized planners, a number of specialism specific beds and some combined beds and finally, a predetermined number of beds per specialisms, but this number must differ per day.

Other aspects

During the interviews some other, more practical, aspects were mentioned. It would be useful if the results would be printable and downloadable to Excel. In that way you can also discuss it afterwards and control for management becomes easier.

The tool should give individual results, so per planner or team. It should not be possible to see the results of other departments.

Flexibility is also very important. An example that was given is the number of available beds. This number is smaller during reduction periods.

A final thing mentioned is the aspects on which the planners are judged by management and by specialists. Completely occupying the OR blocks has priority. Without changing this it is not possible for the planners to focus more on the effects on the wards. This aspect was mentioned by all the planners we interviewed.

## 4.3 Conceptual model

The aspects mentioned about the tool in the previous sections can be combined into a conceptual model of the tool. The figures in Appendix F show a concept version of the layout of the tool. The first figure shows the results tab. This tab gives a total number for the quality of the schedule and per indicator it shows the performance and an explanation in a graph. The second figure shows the layout of the second tab, which concerns trends. For the total quality and per indicator it shows the trend in earlier calculated results and in the realized performance. The final figure gives the layout of the settings tab. Here all the aspects that can be changed will be displayed.

Next to this layout, the previous sections give some other requirements for the tool, which are summarized below:

1. *Flexibility*
   The tool should be flexible. It should be possible that settings differ per specialism and per ward, but they should also be flexible over time. Examples of such settings are the wards per specialism, the weighting factors for the different indicators, the norms per indicator, the number of available beds and the scheduling horizon.
2. *Simple*
   The tool should not be too complex. This means that it is easy to understand for the admissions planners, but also that it does not require much time to use it.
3. *Feasible for a future schedule and for schedules already performed*
   It should be possible to calculate the quality of a schedule for over a few weeks, so for a schedule that is not complete because of emergencies etc. However, also a previous schedule should be possible as input for the tool.

4. *Uses data from iZis*
   The tool should use the data from the current scheduling program, iZis.
5. *Individual results*
   The tool should give results per planner or planning team. According to one of the planners it should not be possible to see the results of others. However, the department Patient Logistics does not agree to this, it would be good if planners could compare their performance to that of others.
6. *Results visible for management*
   The results should also be visible for the management of a specialism, such that it can be used as management information.
7. *Ability to download data to Excel*
   It should also be possible to download the data to Excel. This has to do with the previous requirement. If it is possible to download the data to Excel, it can be used as management information even more.
8. *Printable results*
   Admissions planners also want to use the information during progress meetings. For this it would be useful if they could print the results.
9. *Applicable in the new hospital*
   Because Isala Klinieken moves to a new building, it is important that the tool will also be applicable there. To reach this it is should be easy to change the current wards into the new larger wards in the new hospital. These new larger wards will be used by multiple specialisms. However, we do not focus on that, because there will probably a central planning team per ward.

This chapter described how the tool should present the performance measures determined in Chapter 3. Appendix F shows figures of the conceptual model and above a list of other requirements is given. This describes the ideal situation for the proposed tool. We only develop part of this tool and future research is necessary to determine if all these aspects described are needed to make the tool useful in the hospital. The next step is to forecast the data needed for the performance indicators. The next chapter starts with this by looking for existing models from literature.

# Chapter 5 – Existing models from literature

Now the performance indicators and the expectations of the tool are clear, it is time to start thinking about the model that has to forecast the data necessary. We could of course construct a model completely from scratch and do everything ourselves, but why reinvent the wheel? Maybe there are already some models that generate insights in the effects of an admissions schedule. At least models exists that combine admissions schedules with the processes at the wards, those we can use as a starting point. We start this literature search with some surveys in the area of health care logistics. These surveys are described in Section 5.1. From these surveys we composed a list of articles that could be interesting in this research. These articles are discussed in Section 5.2.

## 5.1 Surveys

We use three surveys about health care logistics that mention the interaction between admissions or ORs and wards. The first one is an article of Vanberkel et al. (2009). They state that articles often focus on a single department and they give an overview of articles that discuss the relationship between different departments. In total they found 88 articles that describe such a relationship. The relationship between the OR and the ward is found in 29 of the articles.

The next survey is from Cardoen et al. (2010). The article focuses on literature about operating room planning and scheduling. The different articles are analyzed in different ways. One way is to look at the performance criteria. Ten articles discuss the performance for wards.

The final survey is written by Guerriero and Guido (2011). This article discusses how operational research can be used in planning and scheduling for the ORs. Hereby, the focus is on mathematical models. A distinction is made between articles that propose a model on a tactical level and articles with a model on an operational level. On a tactical level they find six articles that have leveling of wards and bed occupancy as an objective and on the operational level there are two articles that have the number of beds used as a criterion.

## 5.2 Articles

Although this research focuses on the operational level, most articles about the interaction between admissions schedules and wards focus on higher hierarchical levels. There is one article that focuses on the strategic level and fifteen articles about the tactical level. The models in these articles will not be immediately applicable for our research. However, we could use it, or part of it, as a starting point for our model. There are five articles that do focus on the operational level.

The articles use different approaches for analyzing the interaction between admissions schedules and wards; this gives ideas for approaches in our model. Some articles generate a schedule while others just evaluate them. The goal of this research is not to generate a schedule, but aspects from research projects that do this could still be useful. Table 5.1 gives an overview of the articles. It indicates per article which approach is used, whether a schedule is generated, a short description of the subject and whether it useful for our model.

Although all these articles discuss the interaction between admissions schedules and wards, only a few contain aspects we can use in this research. The main reason that some articles are not applicable is their focus. Some of the articles focus on optimization (Beliën & Demeulemeester, 2007; Beliën & Demeulemeester, 2008; Cardoen, Demeulemeester, & Beliën, 2009; Bekker & Koeleman, 2011; Santibáñez, Begen, & Atkins, 2007). In that forecasting the effects of a schedule is also necessary, but doing this in an innovative way is not the main focus. Other articles focus on multiple consequences of an admissions schedule (Adan & Vissers, 2002; Adan, Bekkers, Dellaert, Vissers, & Yu, 2009; Van Oostrum, Van Houdenhoven, Hurink, Hans, Wullink, & Kazemier, 2006; Beliën, Demeulemeester, & Cardoen, 2006). Therefore they often use a simple, straightforward calculation is used per aspect. Next to the focus of the articles also the approach may cause that is not applicable here. In some of the articles simulation is used (Griffiths, Price-Lloyd, Smithies, & Williams, 2005; Kim & Horowitz, 2002; Cochran & Bharti, 2006). It is possible to forecast the effects of an admissions schedule by simulation. However, like mentioned in Chapter 4, one of the constraints for the tool is that it should give the results fast. With simulation this is not possible. Final drawbacks of some of the articles are that the explanation is not extensive enough (Adan, Bekkers, Dellaert, Jeunet, & Vissers, 2011; Santibáñez, Begen, & Atkins, 2007; Cochran & Bharti, 2006) or that it does not fit the situation of our problem (Elkhuizen, Bor, Smeenk, Klazinga, & Bakker, 2007; de Bruin, Bekker, van Zanten, & Koole, 2010).

Five of the articles mentioned in the table are useful for this research. We now discuss these articles in more detail. The article of Harrison et al. (2005) describes a simulation model that forecasts the mean and the variability of the utilization on a hospital level. The forecast is used to predict the ranges for beds needed in the future and to test if a change in the number of beds needed is an actual change or if it is just part of the normal fluctuations. They try to find a theoretical distribution for the empirical data of admissions and discharges. For the admissions a Poisson process with different mean arrival rates for each day of the week is used. The distribution for the discharges is more complex. For this multiple stages are defined. In every stage there are certain probabilities that a patient is discharged, that the patient stays in this stage and that the patient goes to the next stage. The last stages correspond to the patients that have the longest length of stay. In our model we could use this idea to predict when a patient is discharged. Next to this we could investigate the idea of a Poisson process with a different mean for each day of the week for the emergency patients.

Harris (1986) also gives a simulation model. This model is meant for decisions on a tactical level. The input for the model is a timetable for the ORs. This gives per OR block how many major, intermediate and minor surgeries should be performed. Also the bed limits and the distribution for the length of stay per surgery type are used as input. The output of the model is the bed requirements, the occupancy and the number of cancellations. To find the distribution for the length of stay historical data and the input of the user is used to determine the minimum, mean and maximum length of stay. These are converted into a cumulative distribution. We could use this idea for our model.

The model of Vanberkel et al. (2011a) gives the distribution for the number of used beds based on the MSS. The inputs for the model are the MSS and empirical distributions for the number of patients in an OR block and the length of stay per specialty. The model consists of three steps, determining the distribution for a single block, for one MSS cycle and the steady state distributions for continuous cycles. This final distribution can be used to determine how many beds are needed when you accept a certain probability of not having enough beds. Multiple students supplemented this model (Bosch, 2011; Smeenk, 2011; Vlijm, 2011; Vollebregt, 2011). We can use the research of Smeenk (2011) for our tool. He adapted the model such that it gives distribution of the number of used beds per hour instead of per day. The main difference is that in our situation there is much more certainty about the number of patients and the length of stay, because the treatments for patients are known.

**Table 5.1 - Overview articles**

| Article | Approach | Generate schedule? | Subject | Useful for our model? |
|---|---|---|---|---|
| **Strategic level** | | | | |
| Harrison et al. (2005) | Simulation | No | Correctly forecasting the variability in the occupancy level of beds | Yes |
| **Tactical level** | | | | |
| Adan and Vissers (2002) | ILP | Yes | Admission profile to reach target utilization of resources | No |
| Adan et al. (2009) | ILP | Yes | Include stochastic length of stay in model Adan and Vissers (2002) | No |
| Bekker and Koeleman (2011) | Queuing and Quadratic programming | No | Determine admissions quota and analyzing the impact of variability in admissions on the bed capacity | No |
| Beliën et al. (2006) | Visualization by software system | No | Visualization of impact of MSS on demand for multiple resources | No |
| Beliën and Demeulemeester (2007) | ILP | Yes | Multiple models to construct MSS to minimize expected total bed shortage | No |
| Beliën and Demeulemeester (2008) | ILP, column generation | Yes | Select surgery schedule that minimizes required number of nurses | No |
| Cochran and Bharti (2006) | Queuing and simulation | No | Making clear the complex situation of bed planning. | No |
| De Bruin et al. (2010) | Queuing theory | No | Evaluating current size of wards using the Erlang Loss model | No |
| Elkhuizen et al. (2007) | Spreadsheet calculations | No | Capacity model that gives insight in the required nursing staff per shift | No |
| Harris (1986) | Simulation | No | Predict the daily bed requirements and cancellations based on a cyclic timetable of operations | Yes |
| Kim and Horowitz (2002) | Simulation | No | Analyzing the effects of a daily quota system and reserving beds for elective patients on the performance of ICU | No |
| Santibáñez (2007) | ILP | Yes | Schedule surgical blocks for specialties considering amongst other things post-surgical resource constraints | No |
| Van Oostrum et al. (2006) | ILP, column generation | Yes | MSS to maximize OR utilization and level beds | No |
| Vanberkel et al. (2011a) | Analytical, statistical model | No | Computing downstream workload distribution as a function of an MSS | Yes |
| Vanberkel et al. (2011b) | Qualitative schedule generation | Yes | Use model Vanberkel et al. (2011a) to evaluate proposals for a new MSS | No |
| **Operational level** | | | | |
| Adan et al. (2011) | MILP and decision rules | No | Translation of tactical plans into operational plans | No |
| Cardoen et al. (2009) | Column generation | Yes | Optimizing sequence of surgeries based on multiple objectives | No |
| Griffiths et al. (2005) | Simulation model | No | Calculate the number of nurses needed per shift such that what-if analyses can be performed | No |
| Kusters and Groot (1996) | Analytical model | No | Prediction of resource availability | Yes |
| Littig and Isken (2007) | Analytical model | No | Short-term occupancy prediction | Yes |

Kusters and Groot (1996) give a prediction of the availability of the resources beds, nursing staff and ORs. Only the first two might be interesting for our model. The predictions are used as decision support for the admissions planners. Each of the resources is split into different distributions that can be added up. For the number of beds this is for example waiting list admissions, emergency admissions, discharges from patients that are already in the hospital, discharges from scheduled admissions and discharges from emergency admissions. Per aspect the mean and variation are calculated. After implementing the model it appeared that the variability in occupancy of the OR decreased, but the variability in occupancy of beds increased. From this research especially the idea of splitting the calculations in different parts that can be added, might be interesting for our model.

The article of Littig et al. (2007) also gives predictions for the bed occupancy levels. Like the article of Kusters and Groot (1996), this article splits the admission and discharge flows in multiple aspects that can be added. Next to that it especially focuses on getting the correct data for the calculations.

From this literature review we can conclude that there is already much research performed about the interaction between admissions schedules and wards. However, most of these articles focus on the tactical level. It appears that forecasting what will happen on the wards based on an admissions schedule on an operational level has not yet been the subject of many articles. In the next chapter we combine this literature review and the conclusions from the previous two chapters into our own tool.

# Chapter 6 - Tool for insights about the wards

Previous chapters discussed some aspects that are needed to construct the final tool. This chapter combines this information and gives a description of the tool. Section 6.1 builds upon the ideas for forecast models given in Chapter 5 such that these can be used in our situation. As can be seen in the conceptual model in Chapter 4, the tool should also indicate a rating for the total quality of an admissions schedule. For this to be possible, we need to know how to summarize the numbers of the different indicators into one rating for the total quality. Section 6.2 describes this integration of the indicators. Section 6.3 gives a description of the tool, of how it is developed and it discusses its verification and validation.

## 6.1 Forecasts

Table 3.10 gave a list of variables that should be forecasted to be able to calculate the performance measures. In this section we explain per aspect how the tool forecasts it. Some forecasts are a combination of calculations for day care patients and clinical patients. This distinction needs to be made because the discharge process differs. Clinical patients always stay at least one night and the discharge time does not depend on the length of stay of the patient, while day care patients only stay a few hours and therefore the discharge time depends on the length of stay. A distinction between day care and clinical patients is necessary if discharges are involved in the calculations. Another difference between the forecasts is that some are based on a combination of scheduled and non-scheduled patients. This distinction between scheduled and non-scheduled patients is not necessary if the forecast depends on results of other forecasts or if we do not take into account non-scheduled admissions. Table 6.1 shows which forecasts are calculated in which way. Appendix G gives an overview of the notations we use in the formulas in this section.

Table 6.1 – Division forecasts

| | | Combination of day care and clinical patients | |
|---|---|---|---|
| | | No | Yes |
| Combination of scheduled and non-scheduled patients | No | Expected times between scheduled admissions (6.1.1) | Expected number of used beds per hour (6.1.5)<br>Expected number of patients per hour, for each reason of admission and for each number of days already in the hospital (6.1.6) |
| | Yes | Expected number of admissions (6.1.2) | Distribution of the number of used beds per hour (6.1.3)<br>Expected number of discharges (6.1.4) |

### 6.1.1 Expected times between scheduled admissions

Because the exact arrival times of non-scheduled admissions are difficult to forecast, we only consider the scheduled admissions when calculating the expected times between admissions. The times of admissions can be determined from the data from the scheduling program. A problem with this is that if all admissions are scheduled at the same time, there would be no variability in the times between the admissions. However, this would not be a representation of the quality for the wards; if all patients would arrive at for example 10 am it is not ideal for the ward. To avoid this we use the start and the end of the day as dummy admissions. For clinical wards it should be indicated in the settings between which hours of the day scheduled admissions could take place. These are then used as the start and end of the day.

### 6.1.2 Expected number of admissions

We need to know the expected number of admissions per hour, $E[a_{m,t}^{w}]$, and per day, $E[a_{m}^{w}]$. In this w is the ward, m is the day in the scheduling horizon and t is the timeslot (in this case the hour). Both of these forecasts can be calculated by adding the scheduled and non-scheduled admissions.

The number of scheduled admissions per hour, $E[sa_{m,t}^{w}]$, can be determined from the data of the scheduling program. The number of scheduled admissions per day is the sum of the number per hour.

We assume, without loss of generality, that there is a constant pattern in the expected number of non-scheduled admissions over the week. Therefore, we determine per weekday r the expected number of non-scheduled admissions, $E[nsa_{r}^{w}]$, based on historical data. We also assume, without loss of generality, that the distribution of the admissions over the day does not depend on the day. So we divide the expected number of non-scheduled admissions over the hours in a way that is equal for all days, $perca_{t}^{w}$. This distribution can be determined based on historical data.

The formulas for the expected number of admissions per hour and per day are then as follows. In this Q is the last day of the scheduling horizon and T is the number of time slots per day.

$$E[a_{m,t}^{w}] = E[sa_{m,t}^{w}] + \left(E[nsa_{r}^{w}] * perca_{t}^{w}\right) \qquad \text{for m=0,...,Q; t=0,...,T-1; } \forall \text{ w}$$

$$E[a_{m}^{w}] = \sum_{t=0}^{T-1} E[sa_{m,t}^{w}] + E[nsa_{r}^{w}] \qquad \text{for m=0,...,Q; } \forall \text{ w}$$

### 6.1.3 Distribution of the number of used beds per hour

This section describes the distribution of the number of used beds per hour. Smeenk (2011) already reformulated the tactical model of Vanberkel et al. (2011a) such that it determines a distribution per hour. Therefore, we use the model of Smeenk (2011) as a starting point for our calculations. The main difference between our model and the model of Smeenk is that in our case there is no recurring cycle and therefore there are already some patients in the ward at the moment we start calculating. Another aspect that differs is that we have more information about the patients. We know how many scheduled patients will be admitted each day and we know more about the discharge probabilities of those patients because their treatment types are known. A final difference is that Smeenk (2011) differentiates between patients that are admitted on the day of surgery and patients that are admitted the day before. We do not make that distinction.

The calculations for the distribution of the number of used beds per hour are relatively complex and extensive. Therefore we only explain the general idea here, Appendix I describes the calculations in more detail and gives the exact formulas.

The basic idea of the calculations is displayed in Figure 6.1. The total distribution of the number of used beds per hour and per day is calculated by combining the separate distributions for clinical and day care patients. Both of these distributions are calculated by combining the distributions for scheduled and non-scheduled patients. For each of these distributions we group the patients based on their time of admission. For clinical patients this means grouping the patients per admission day and for day care patients per admission hour. At the moment of calculation there are already some patients present at the ward. Day care patient that are already present will not be there anymore the next day so we do not include them. However, clinical patients, scheduled and non-scheduled, might still be there the next day. We treat these patients as a separate group and include them in the calculations for the scheduled clinical patients.

Adding the distributions for scheduled and non-scheduled patients and grouping the patients based on their time of admission is also done in the model of Smeenk (2011). However, making a distinction between clinical and day care patients and considering patients already present is not included in that model. We now discuss the steps needed to calculate the distributions per group of patients.

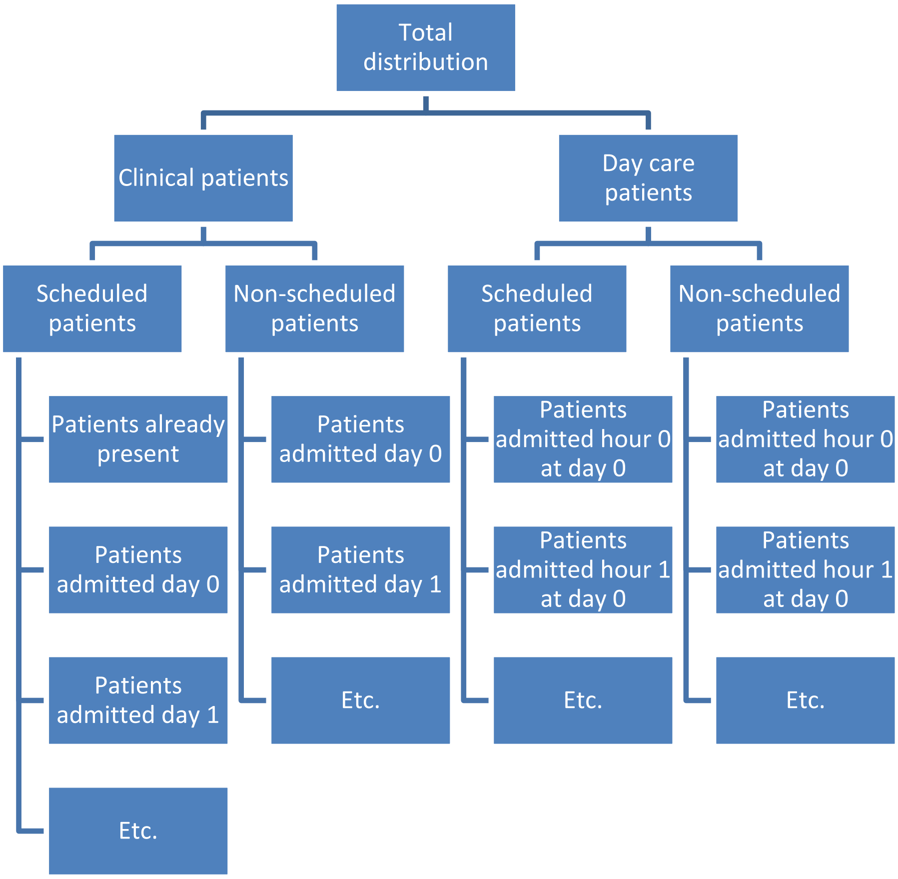


**Figure 6.1 – Overview calculations distributions of the number of used beds per hour**

<u>Calculation steps for groups of scheduled clinical patients</u>

1. *Distribution for the first day, patients already present*

   Until the moment of calculation there is certainty about the number of patients that are already present. After that every patient has a certain probability p to be discharged during a timeslot and a probability 1-p of staying. If there are k patients at the ward, the probability of x patients at the ward during the next period can be calculated using a binomial distribution, $\binom{k}{x}(p)^{k-x}(1-p)^{x}$. We know the distribution for the number of patients at the ward during the previous timeslot. We can use this distribution together with the binomial formula to calculate the distribution for the number of patients at the ward during this timeslot.

2. *Distribution for the day of admission, patients not yet admitted*
   Clinical patients always stay one night, so for the day of admission you know with certainty how many patients there will be on the ward.
3. *Distribution for the other days*
   3.1. *Distribution for the beginning of the day*
      3.1.1. *Distribution for the first day, patients already present*
         Here again we can use a binomial distribution like explained in the first step.
      3.1.2. *Distribution for the day after admission, patients not yet admitted*
         Because no clinical patients are discharged on the day of admission the number of patients at the beginning of the day after admission is known with certainty.
      3.1.3. *Other days*
         For this a binomial distribution can be used as explained earlier. The difference is that we now use a probability that a patient is discharged during a whole day instead of during one timeslot.
   3.2. *Distribution for the rest of the day*
      We use the distribution for the beginning of the day as a starting point and calculate the distributions for the rest of the day again with a binomial distribution using a probability that a patient is discharged during a timeslot.

<u>Calculation steps for groups of non-scheduled clinical patients</u>
The distribution for the non-scheduled patients does not depend on the exact date. However, we do assume that it depends on the weekday. Therefore, we perform the steps described below per weekday and afterwards rewrite it to the dates in the planning horizon.

1. *Distribution for the day of admission*
   1.1. *Distribution for the beginning of the day*
      At the beginning of the day of admission it is certain that there are no patients at the ward.
   1.2. *Distribution for the rest of the day*
      We use a Poisson distribution for the arrival process of non-scheduled patients. On the day of admission no patients are discharged, so this Poisson distribution is sufficient for the calculations.
2. *Distribution for the other days*
   2.1. *Distribution for the beginning of the day*
      2.1.1. *Distribution for the first day after admission*
         Because no patients are discharged during the day of admission we can again use the Poisson distribution.
      2.1.2. *Distribution for the other days*
         These calculations are similar to those for scheduled patients. We use a binomial distribution with a probability that a patient is discharged during a certain day.
   2.2. *Distribution for the rest of the day*
      This is also similar to the scheduled patients. We use a binomial distribution with a probability that a patient is discharged during a time slot.

Calculation steps for groups of scheduled day care patients

The calculations for the groups of day care patients differ from that of the clinical patients because now we use timeslots instead of days. For the clinical patients these days are divided into timeslots, here we do not divide the timeslots into smaller parts. This makes the calculations less complex.

1. *Distribution for the hour of admission*
   We assume that day care patients always stay at the hospital at least one hour. Therefore we know with certainty how many patients are at the ward during the hour of admission.
2. *Distribution for other hours*
   For the other hours we use a binomial distribution with a probability that a patient is discharged during a time slot.

Calculation steps groups of non-scheduled day care patients

For the non-scheduled day care patients we perform the steps per weekday. So afterwards we have to rewrite this for the days in the planning horizon.

1. *Distribution for the hour of admission*
   For the arriving process of non-scheduled patients we use a Poisson distribution.
2. *Distribution for other hours*
   For the other hours we again use a binomial distribution with a probability a patient is discharged during a time slot.

For the binomial distributions we need the probabilities that a patient is discharged during a certain time slot or day. These probabilities are based on the length of stay distributions per treatment type and for the clinical patients on a constant pattern in which discharges are distributed over the day.

### 6.1.4 Expected number of discharges

Literature gives two options to determine the expected number of discharges. The first one is described in the master thesis of Smeenk (2011) and the second option is the multi stage discharge model of Harrison et al. (2005). To determine the distribution for the number of used beds per hour, Section 6.1.3, we used the model of Smeenk (2011). To keep the output and calculations consistent we also use the ideas from this model for the discharges. Although we use the same idea as in the previous section, these calculations are much easier because we need expected values instead of distributions.

Here we also only explain the general idea of the calculations. Appendix J describes it in more detail and gives the exact formulas. The general idea is displayed in Figure 6.2. The discharges of clinical patients are first calculated per day. The discharges of clinical patients per hour are based on this number and on a constant pattern of how the discharges are distributed over the day. For day care patients it is the other way around. First the discharges are calculated per hour and then these are added for the discharges per day.

Again the patients are grouped based on their admission day or hour. The expected numbers of discharges per group of patients are based on the distribution for the length of stay and the expected number of patients in that group.

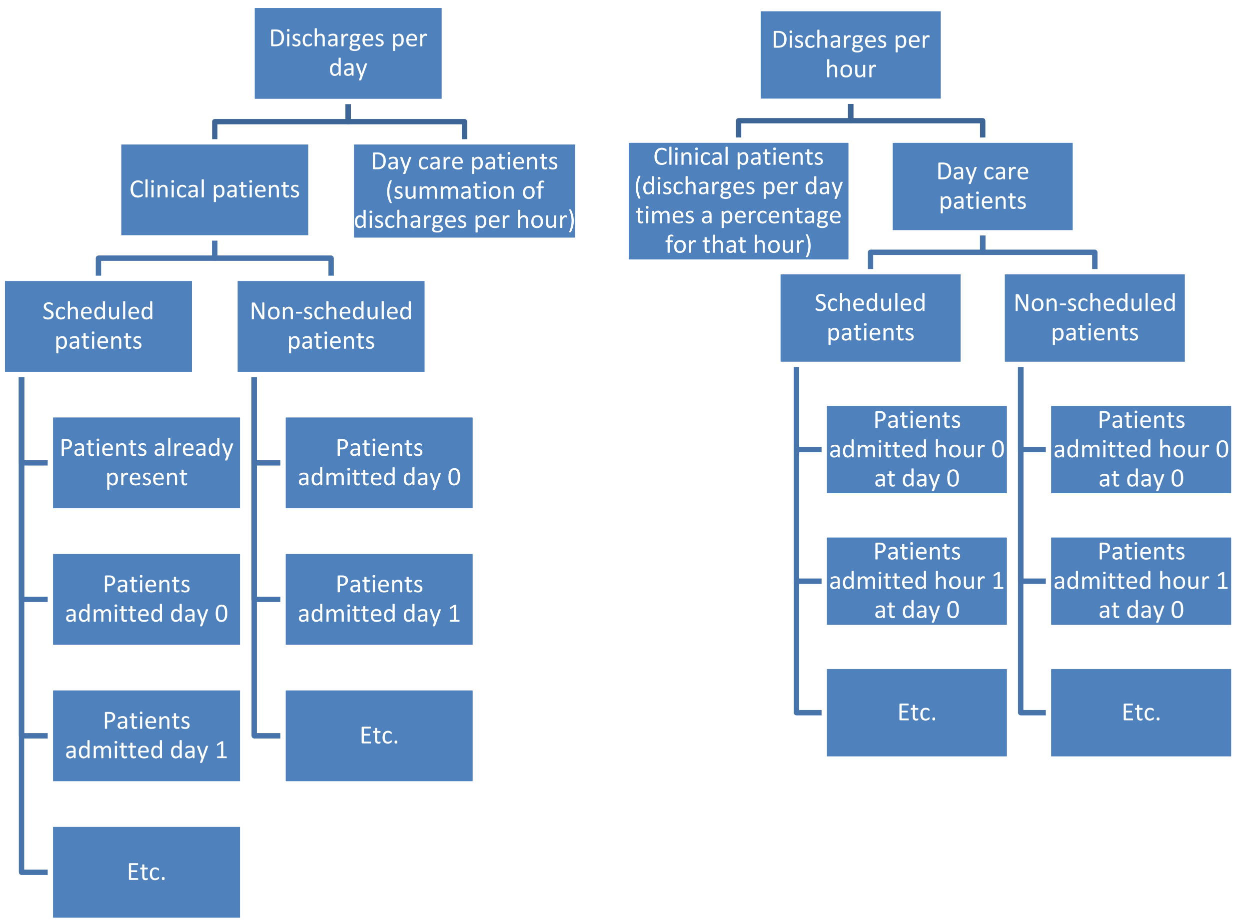


Figure 6.2 – Overview calculations expected number of discharges

### 6.1.5 Expected number of used beds per hour

The expected number of used beds per hour can be calculated based on the numbers from the previous sections. The number of used beds during this hour, $E[b^w_{m,t}]$, is the number of used beds during the previous hour plus the patients that arrived during that hour, the expected number of admissions $E[a^w_{m,t}]$, minus the patients that left, the expected number of discharges $E[d^w_{m,t}]$.

There is a small difference in the calculations for clinical and day care patients. For clinical patients you need to consider the patients that are already in the hospital at the beginning of the day. For day care patients the number of patients at the beginning of the day is zero.

The formulas look like shown below. As a starting point we use the number of used beds at the moment the calculations are performed.

$$E[b^w_{m,t}] = \begin{cases} E[b^w_{m,t-1}] + E[a^w_{m,t-1}] - E[d^w_{m,t-1}] & t > 0 \\ E[b^w_{m-1,T-1}] + E[a^w_{m-1,T-1}] - E[d^w_{m-1,T-1}] & t = 0 \end{cases}$$ for m=0,…,Q; t=0,…,T-1; $\forall$ w

$$E[b'^w_{m,t}] = \begin{cases} E[b'^w_{m,t-1}] + E[a^w_{m,t-1}] - E[d'^w_{m,t-1}] & t > 0 \\ 0 & t = 0 \end{cases}$$ for m=0,…,Q; t=0,…,T-1; $\forall$ w

### 6.1.6 Expected number of patients per hour, for each reason of admission and for each number of days already in the hospital

This section is about the expected number of patients per hour, for each reason of admission, $j$, and for each number of days already in the hospital, $v$.

Day care patients leave before the end of the day, so for these patients the aspect of the number of days already in the hospital does not have to be considered. The formulas are then almost the same as in the previous section. The only difference is that now for the number of admissions and discharges we also need to consider the reason of admission, $E[a_{m,t}^{w,j}]$ and $E[d'^{w,j}_{m,t}]$. However, it might be difficult to forecast the number of non-scheduled patients per reason of admission. Therefore, we treat the non-scheduled patients as a separate reason of admission. The formula for the expected number of day care patients per hour and per reason for admission, $E[b'^{w,j}_{m,t}]$, is:

$$E[b'^{w,j}_{m,t}] = \begin{cases} E[b'^{w,j}_{m,t-1}] + E[a^{w,j}_{m,t-1}] - E[d'^{w,j}_{m,t-1}] & t > 0 \\ 0 & t = 0 \end{cases}$$ for m=0,...,Q; t=0,...,T-1; $\forall$ w; $\forall$ j

For clinical wards the calculations are more difficult, in that case patients stay at least one night in the hospital, so we have to consider the number of days a patient is in the hospital. The patients that are in the hospital at a certain moment of time and are there for the same number of days are all admitted on the same day. At the beginning of the admission day the number of patients of this group is zero. The rest of that day patients are admitted and because it concerns clinical patients, no discharges take place. The next days no patients are admitted anymore, on these days discharges take place. Just like for the day care wards we now need to know the expected number of admissions per reason of admission, $E[a_{m,t}^{w,j}]$. We even need to know the discharges per reason of admission and per number of days the patients are in the hospital, $E[d_{m,t}^{w,j,v}]$. To make it not too complex we treat the non-scheduled patients as a separate reason of admission. The formula for the expected number of clinical patients per hour, per reason for admission and per number of days already in the hospital, $E[b_{m,t}^{w,j,v}]$, is:

$$E[b^{w,j,v}_{m,t}] = \begin{cases} 0 & t = 0, v = 0 \\ E[b^{w,j,v}_{m,t}] + E[a^{w,j}_{m,t-1}] & t > 0, v = 0 \\ E[b^{w,j,v-1}_{m-1,T-1}] - E[d^{w,j,v-1}_{m-1,T-1}] & t = 0, v > 0 \\ E[b^{w,j,v}_{m,t-1}] - E[d^{w,j,v}_{m,t-1}] & t > 0, v > 0 \end{cases}$$ for m=0,...,Q; t=0,...,T-1; $\forall$ w; $\forall$ j; $\forall$ v

## 6.2 Integrating performance measures

With the forecasts from the previous section all data that is needed to calculate the performance measures is available. However, we also need to combine these performance measures to get an aggregate number for the quality of the schedule.

Combining the performance measures is called multi criteria analysis. There are different approaches for this, but most of them require alternatives to be known. In our situation this is not the case, we do not have to make a decision between multiple alternatives; we just want to know the value of one alternative. The method for multi criteria analysis that corresponds to this is constructing a single aggregated objective function. Multiple objectives, $x_j$, are combined into one function, $y$, like shown below.

$$y = f(x_1,...,x_n)$$

Methods that are often used for an aggregated objective function are weighted sum and weighted product. The formulas for these are as follows. In this $w_j$ is the weight for the objective j.

$$weighted\ \ sum = \frac{\sum_{j=1}^{n} w_j x_j}{\sum_{j=1}^{n} w_j}$$

$$weighted\ \ product = \prod_{j=1}^{n} (x_j)^{w_j}$$

A problem of the weighted product model is that the output is not linear. For the tool it is important that the output can easily be interpreted as a number for the quality. This is easier with a linear objective function. For this reason we choose to use the weighted sum model.

For this model we need to rewrite the performance measures such that they are on the same scale. For this we use value functions. This means that the best possible amount for a certain performance measure gets the value one and the worst possible amount gets the value zero. The function for the amount in between needs to be determined by the decision maker. However, this can make it very complex. Therefore we assume a linear value function for all performance measures.

The best and worst possible amounts still need to be determined. The best amounts are straightforward for all performance measures. For the performance measures probability of overutilization and for all measures concerning variability the best possible amount is zero. The other performance measures are utilization and staff productivity, these need to be according to a certain norm. For the objective function we use the deviation from this norm. Therefore the best possible amount here is also zero. The worst possible amounts are more difficult to determine. This will be different per specialism. To determine this we use historical data. During the implementation for a specialism we consider the realization of the performance measures for the past year and determine the worst realization during that year.

Finally also the weights for the performance measures need to be determined. This is very subjective and depends on the opinion of multiple stakeholders. Per performance measure the user of the tool should indicate to which importance category it belongs. Table 6.2 shows the categories with its corresponding weights. Using these weights means that a performance measure which is not at all important will not be taken into account in the total quality and for example a measure that is indicated as very important is twice as important as a measure with the indication neutral.

## 6.3 Tool for insights about the wards

Now all information that is needed to develop the tool is available. Section 6.3.1 describes how we developed the tool. The second section gives the description of the proposed tool. Finally Section 6.3.3 discusses its verification and validation.

Table 6.2 – Importance categories

| Importance | Weight |
|---|---|
| Not at all important | 0 |
| Not important | 1 |
| Neutral | 2 |
| Important | 3 |
| Very important | 4 |

### 6.3.1 Tool development

To avoid mistakes and unnecessary steps we used a software development method. Multiple methods exist for software development. The method we use is Extreme Programming. Extreme Programming is an iterative method for small to medium sized teams (Beck, 2000). The advantage of such an iterative method is that not all requirements need to be known in advance, the project can evolve over time. Extreme Programming is based on a set of principles. The list below gives the most relevant principles for this project (Beck, 2000):

- *Small releases*
  The whole project should be divided into subparts, called stories. During the project already small working parts should be delivered.
- *Simple design*
  In a previous chapter we determined that the tool should be kept simple. This does not only yield for the display, also for the coding behind it.
- *Testing*
  Different parts of the project can only be completed when they run a certain number of tests. This testing should be done by the programmer (unit testing) and by the customer (functional testing).
- *Refactoring*
  A new version of the system should be made by adapting the existing design of the system. After adapting it should still run all the tests.
- *Customer involvement*
  In Extreme Programming the customer should be involved a lot during the development process.

To create small releases the project should be divided into multiple stories. The stories on the highest level are called releases (Beck, 1999). These releases can again be divided into stories, which are called iterations (Beck, 1999). To complete an iteration multiple tasks are needed.

The customers that should be involved in the development are the department Patient Logistics and the admissions planners. Involving admissions planners of all specialisms would become too complex. Therefore we only include the planner of Urology in this process. The customers are involved in testing the iterations and releases. Next to that, the department Patient Logistics is involved in selecting the stories for the releases and iterations. In this way we make sure that the most important aspects are completed first.

Our tool can be divided into three main parts, the results, the trends and the settings. The settings and the results are very dependent on each other. So they cannot be seen as different releases. However, the results and settings together can be developed without the trends tab. We chose to focus on the release results/settings first. This is the only possible sequence because the trends depend on the results. While looking at the available data from the scheduling program it becomes clear that information about future schedules is stored differently than information about schedules that are already performed. We choose the future schedules as the sub release we focus on first. These decisions are made together with the department Patient Logistics. The results and settings for schedules in the future can be divided into iterations by looking at the different indicators. Because of time constraints we are not able to perform all these iterations. Together with the department Patient Logistics we decided to focus on the indicators admissions over the week and overutilization. The ward of Urology is a clinical ward, but sometimes also day care patients are admitted. Therefore the calculation of the forecasts should be suitable for the combination of clinical and day care patients. Figure 6.3 gives an overview of the releases and iterations just mentioned. Each iteration can be divided into multiple tasks.

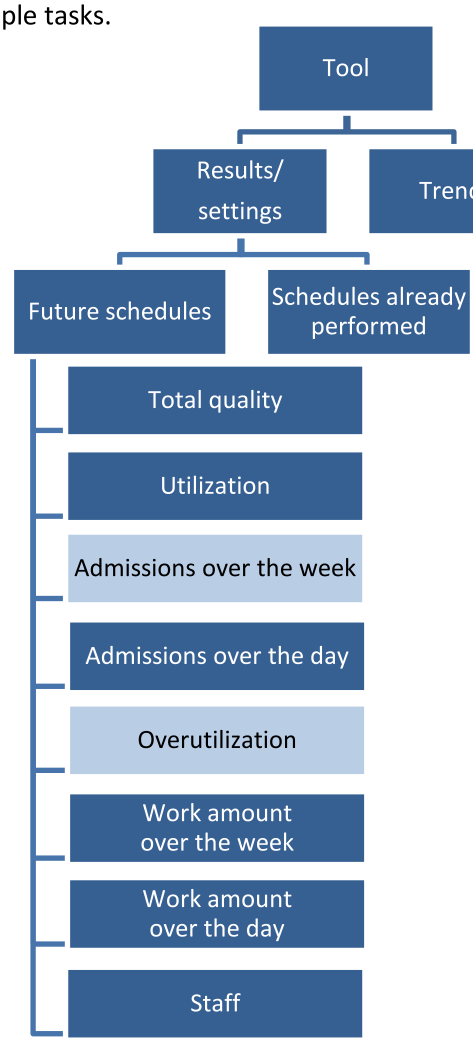


**Figure 6.3 – Releases and iterations**

Because the tool will not be complete at the end of this research, it is important that the department Patient Logistics is able to continue developing the tool. For this reason we program the tool in VBA in Excel.

### 6.3.2 Tool description

We developed part of the proposed tool like described in the previous section. Figure 6.4 and Figure 6.5 show how this tool looks like. The text in the figures is in Dutch, because this version of the tool is actually used by the admissions planner of Urology. The tool can be used as follows. First Excel documents need to be downloaded from the scheduling program, iZis. These are documents with information about the scheduled patients and about the patients that are already at the ward. Next the tool can be opened and some settings might be changed, like the scheduling horizon. When the admissions planner presses the button 'Bereken' ('Calculate'), the tool reads the data from the downloaded Excel documents, calculates the variables needed and shows it in the charts. After calculation the button 'Grafieken versturen' ('Send charts') becomes visible. Pressing this buttons opens an email message with an Excel document with the charts as an attachment. This makes it possible for the admissions planner to send the charts to for example the ward or management. If the tool is closed the calculated data is saved in the Excel sheet, such that it can be used for validation, which is described in the next section.

Until now we used the tool to get the data for the ward of Urology for one week in advance. When we do not save sub results for verification the calculation time is only a few seconds. Urology has a relatively small ward. For specialisms with larger wards the calculation time will be longer.

### 6.3.3 Tool verification and validation

To make sure the tool shows the correct information to the planners we need to verify and validate the tool. Because we only programmed part of the tool, we only verify and validate this part.

First we verify the tool to make sure the calculations in the tool correspond to the mathematical formulas discussed earlier in this chapter. This was already one of the attention points when testing of the software development. Additional verification is done by calculating (sub) results by hand (using Excel) and comparing this to the output of the tool. For the admissions over the week the verification is relatively simple, but for the overutilization it is more complex. Therefore, we save as much sub results as possible in the Excel sheets. For some sub results we simplified the input of the model. During the verification some small changes were needed, but at the end the sub results were as expected when looking at the mathematical model.

The next step is to validate the tool, this means checking whether the output of the tool corresponds to the realization. The problem with this is that the realization can be influenced by other factors than the admissions schedule, for example by decisions made at the OR or the ward. We also validate the tool in another way, namely discussing it with the admissions planners and the ward, this is called face validity. Validation is already partly done by the admissions planner when testing the tool. However, it is important that the output of the tool represents the experiences at the wards.

For the validation of the admissions over the week we compare the output of the tool with the actual number of admissions over the week. We used the tool for a few weeks for Urology. The output of the tool and the realization is shown in Figure 6.6. From this it seems that the pattern in the expected number of admissions is similar to that in the actual number of admissions. This is also recognized by the employees at the ward. The deviations are mainly due to non-scheduled patients and no shows. The mean absolute percentage error for the expected number of admissions is 30%. To be more certain about the correctness more data is needed.

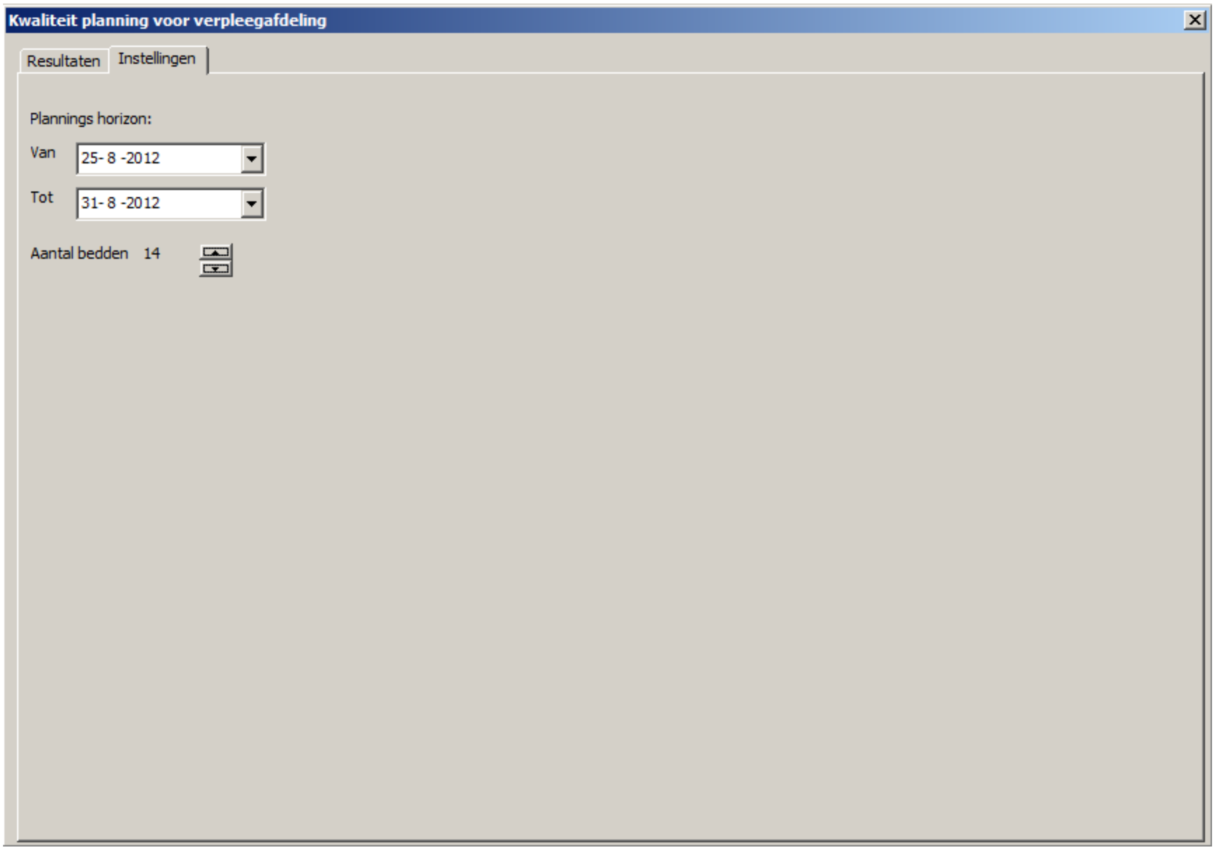

Figure 6.4 – Print screen proposed tool (settings tab)

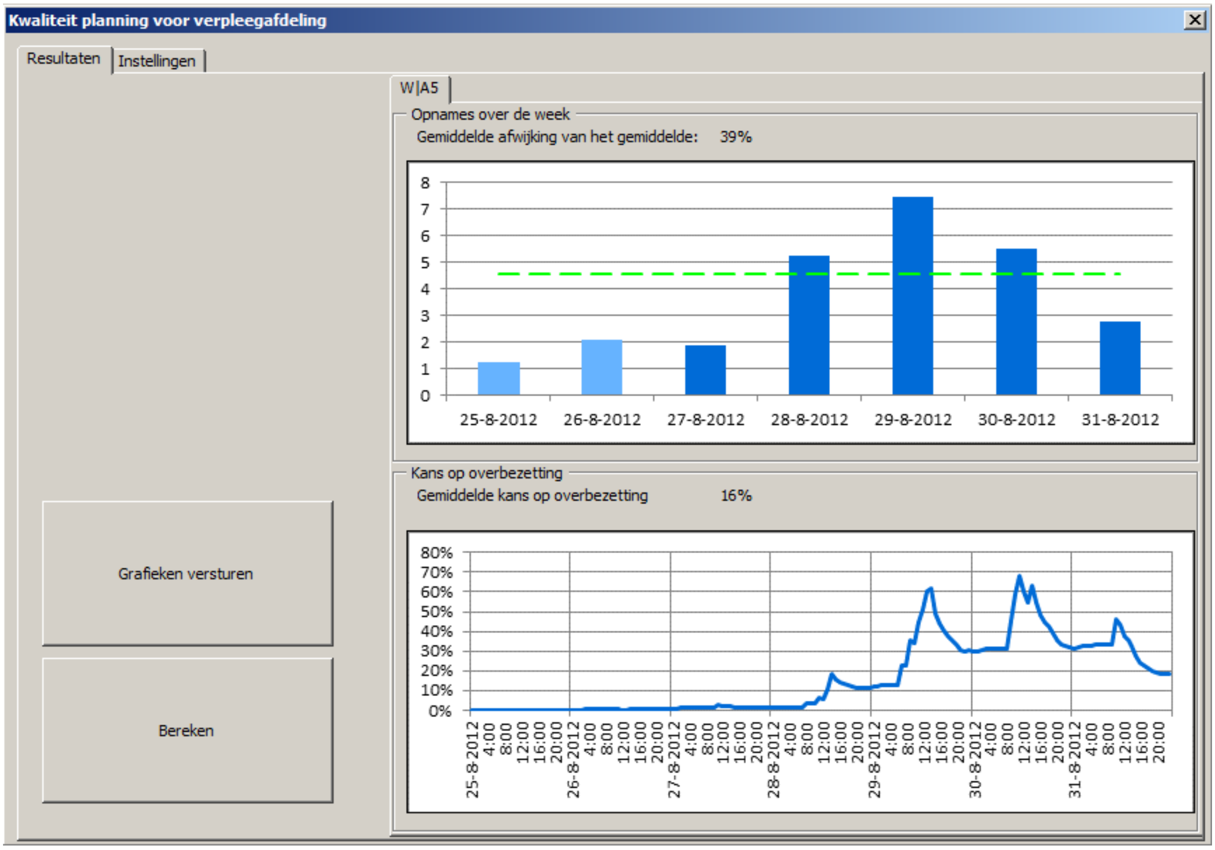

Figure 6.5 – Print screen proposed tool (results tab)

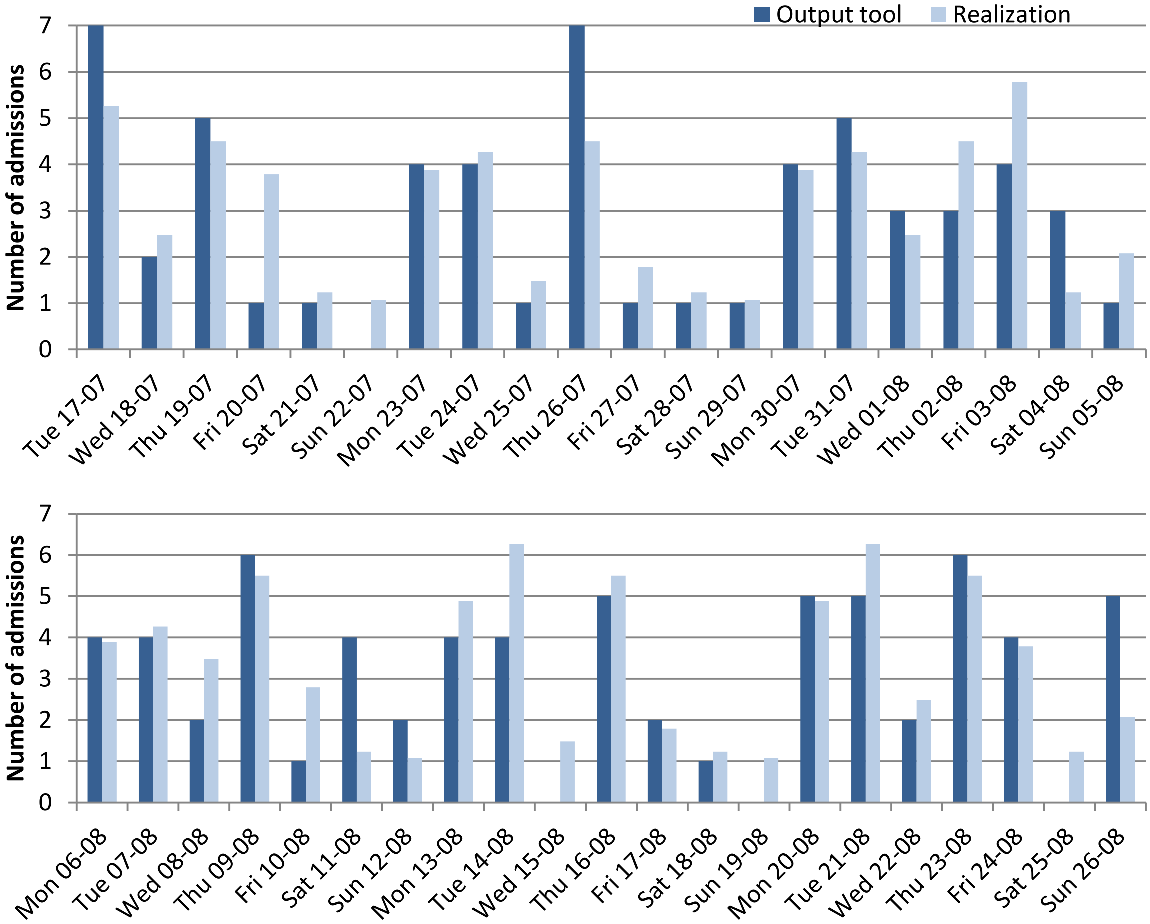


**Figure 6.6 – Validation expected number of admissions over the week**

Figure 6.7 shows the probability of overutilization for the Urology ward for the period during which we used the tool. The vertical lines are the moments on which new forecasts are calculated. On these moments the probability of overutilization decreases. This is logical because on these moments there is more certainty about the number of patients at the ward then when you have to predict it a week ahead. The employees at the ward recognized the pattern in the probability of overutilization. At the end of the week it is often most difficult to arrange everything. The output of the tool shows that during the day the largest probability of overutilization is often at the beginning of the afternoon, this is also recognized by the ward.

The probability of overutilization cannot be compared to the realization data as easily as the number of admissions. In the realization the probability of overutilization is just 0% or 100%. To validate it we divide the scale of probability of overutilization in five intervals, 0%-20% etc., and calculate per interval during which percentage of the hours there was overutilization. We expect that in the intervals with higher probabilities, overutilization would occur more often. The results are shown in Figure 6.8. For the first four intervals our expectations seem to be correct. However, for probabilities of overutilization between 80% and 100% overutilization occurs less often. An explanation for this might be that when there is a large probability of overutilization, the wards recognize this and make changes to the schedules to prevent overutilization. With a smaller probability of overutilization the pressure to change the schedule might not be large enough. The period for which we used the tool is relatively small. To be more certain about the validity of the output of the tool more data is necessary.

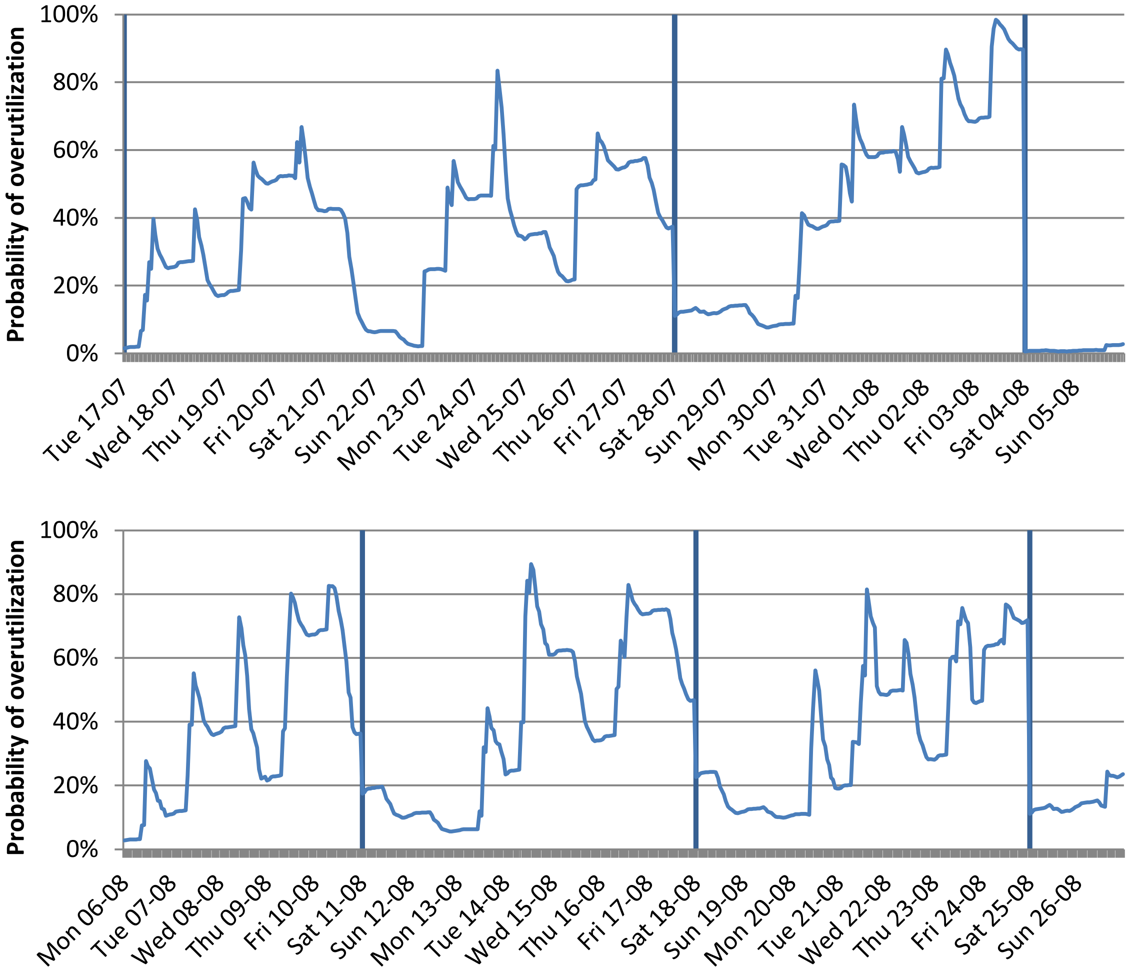


**Figure 6.7 – Probability of overutilization Urology**

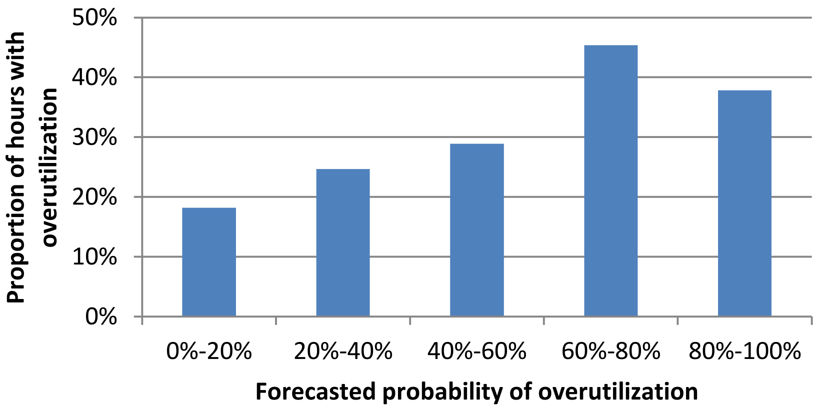


**Figure 6.8 – Validation probability of overutilization**

In this chapter we described how to forecast the data needed to calculate the performance measures. Next to that we discussed how to combine the performance measures into a rating for the total quality using the weighted sum method. And finally we developed part of the tool using Extreme Programming. From the verification and validation it became clear that the tool generates useful output for the admissions planner. Although we already developed part of the tool this should of course not be the end of the project. Eventually a complete tool should be used by all admissions planners in the hospital. The next chapter discusses how to reach this.

# Chapter 7 - Implementation

Although the tool is not yet ready to be implemented we do describe an implementation plan for the tool. Section 7.1 describes the steps that should be taken after this research and Section 7.2 discusses the stakeholders that are involved.

## 7.1 Implementation steps

This section describes the steps that are needed during the implementation.

1. Develop the tool

The first step should be to complete the tool. This means programming the remaining releases and iterations displayed in Figure 6.1. This development should be done according to the software development method described in Section 6.3.

2. Test tool within one specialism

Testing the tool was already part of the development phase. However, also after that the tool should be used within one specialism for some time before continuing the implementation. This period could especially be used to collect enough information for the next step in the implementation.

3. Convince hospital management

Support from the management of the hospital is very important to successfully implement the tool in the whole hospital. This support is needed to get resources for the rest of the implementation. Management should be convinced that the tool has enough advantages for the hospital.

4. Create urgency

Currently, the main focus when scheduling admissions is completely filling the operating rooms. The goal of the tool is to let the admissions planners also consider the wards. However, if they will be judged on the quality of their schedule for the operating rooms there will be no urgency for them to use the tool. This change in focus should be initiated on a strategic level. Hospital management should support it and communicate it to the rest of the organization.

5. Develop the tool in current software

We programmed the first version of the tool in VBA in Excel. However, this is not an appropriate programming environment when implementing an application into the whole organization. The best solution would be to integrate the tool in the current applications of the hospital.

6. Implement the tool for all specialisms

The next step is to implement it in the whole organization. This should not be done for the whole organization at the same time, but in such a way that enough support can be given to the users. This implementation step consists of multiple sub steps.

> 1. Convince management
>
> Also within one specialism support of management is very important. Management should make sure that the focus is more on wards, like explained in Section 7.1.4.
>
> 2. Inform employees
>
> In the previous step we already mentioned management, but also other employees should be informed about the implementation of the tool. For example employees on the wards and specialists, they are not directly involved in using the tool, but they could experience the consequences when admissions planners schedule differently when using the tool.

3. Make the tool suitable

The tool is developed in such a way that it is applicable for most of the specialisms. However, per specialism specific settings might be needed and they might use it in a different way.

4. Train users

The admissions planners will be the people that actually use the tool. They should be trained for this. The information that the tool gives is new to them, so the training should not only focus on using the tool, but also on interpreting the output. Next to the admissions planners, management could also get valuable information from the tool. Therefore they should also be informed about the way in which they can use the output.

5. Use the tool

The final step in the implementation per specialism is to actually let the admissions planners use the tool. It would be best not to let them use all indicators in the tool at once. Only showing a few of the indicators at first lets them get used to the new way of working.

7. Monitoring

After the tool is implemented in the whole organization the project is not complete. The final step is monitoring. During this step problems in the usage of the tool should be solved. It also should be made sure that everyone uses the tool in the right way. Finally the tool should continuously be improved. We discuss some ideas for this in Section 8.3 in the next chapter.

## 7.2 Stakeholder analysis

During the implementation steps discussed in the previous section multiple stakeholders are involved. Figure 7.1 displays these stakeholders in a framework which is based on the model of Mitchell et al. (1997). We estimated per stakeholder their involvement, their influence and their opinion about this project. The position of the stakeholders within this framework indicates how to cope with them during the project.

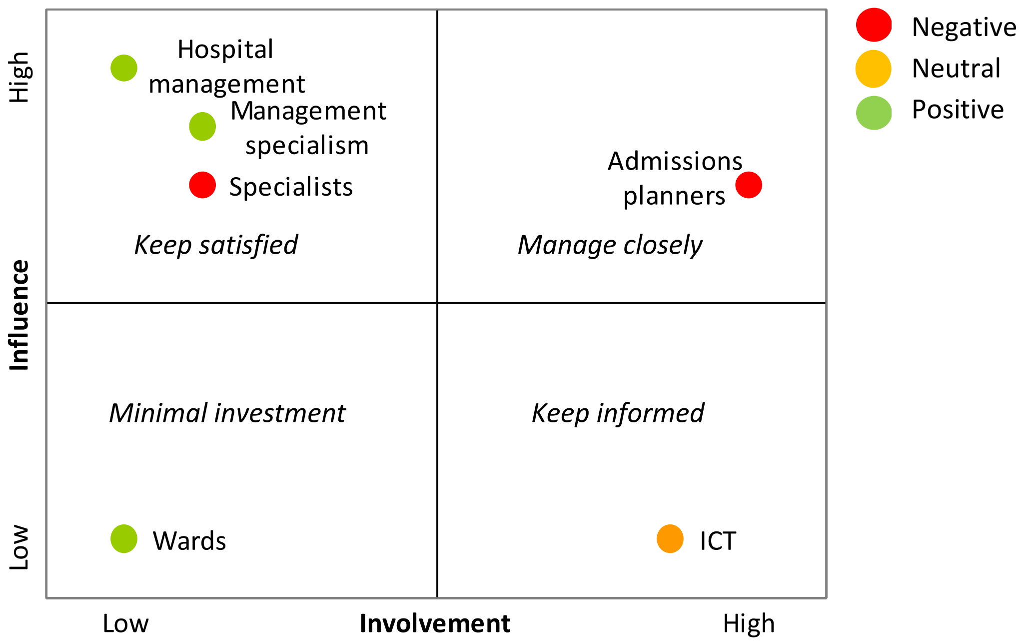


Figure 7.1 – Stakeholder analysis

The implementation is the final step in the project. In the next chapter we look back with some conclusions and a discussion, but we also look ahead; what are topics for future research?

# Chapter 8 - Conclusion and recommendations

In the beginning of this research we determined the main objective for the project. Now it is time to reflect on this. Section 8.1 gives the main conclusions from our research. The discussion in Section 8.2 describes the value of the research, but also its shortcomings. Finally, Section 8.3 discusses our recommendations for Isala Klinieken.

## 8.1 Conclusions

In Chapter 1 of this report we formulated the objective of this research as:

*Generating insights in the effects of operational offline scheduling decisions made for hospital admissions on the capacity planning processes at the wards.*

During the research it became clear that these insights should be given by using a tool that shows the admissions planners the quality of their schedule. It requires three steps to get from an admissions schedule to the insights for the planners. First multiple aspects of the wards need to be forecasted based on the schedule. Next the forecasts should be summarized into performance measures. Finally the performance measures need to be displayed to the admissions planners.

This research was divided according to these required steps. We started with the performance measures. Based on interviews and a survey on all hierarchical levels within Isala Klinieken we constructed a list of performance measures which are important for the wards. This resulted in a long list of performance measures. Therefore, we reduced this list by using evaluation criteria and by looking at the importance based on the interviews and the survey. Finally we can conclude that the performance measures that should be shown to the admissions planners are:

- Average utilization per ward
- Variability in the number of used beds over the week
- Staff productivity
- Variability in amount of work during the day
- Constant pattern in amount of work over the week
- Variability in admissions during the day
- Variability in admissions over the week
- Staff availability
- Overutilization per ward
- Overutilization on certain moments of the day

To determine how these performance measures should be displayed to the admissions planners, we interviewed multiple planners and the department Patient Logistics. It became clear that the tool should summarize the performance measures into a rating for the total quality of a schedule. Next to this the tool should show the trends of the total quality and of the performance measures. Another important requirement for the tool is that it should be flexible. This is translated into a possibility for admissions planners to change multiple settings in the tool.

To determine the performance measures from an admissions schedule, multiple forecasts are needed. The most complex forecasts are the expected number of discharges and the distribution for the number of used beds per hour. We based the calculations of these forecasts on the model of Smeenk (2011).

Because of time constraints we were only able to develop part of the tool, namely the results for the admissions over the week and the overutilization for future schedules. We did this development according to the software development method Extreme Programming. During the development the tool was tested by the admissions planner of Urology. From the verification and validation it became clear that the tool generates useful output for the admissions planner. Therefore, we can conclude that it is possible to generate insights in the effects of scheduling decisions made for hospital admissions on the capacity planning processes at the wards.

## 8.2 Discussion

With the proposed tool from this research Isala Klinieken has an indication of the quality of an admissions schedule on the operational offline level. This is a new way of working in hospitals. Currently people mostly look at realization data to evaluate the quality of processes. There are some developments in forecasting on the operational online level, but not yet on the offline level. Like concluded in the literature review in Chapter 5, research about the interaction of ORs and wards often focuses on the tactical level. So also in that field this point of view is relatively new.

We performed our research for Isala Klinieken and therefore we only used information from this hospital. Because of this we cannot conclude something about the external validity of the research, more research in multiple hospitals is needed for this.

If we would need to perform this research again, we would probably do some things differently. First, it would be better to design the interviews and survey in Chapter 3 in a more structured way. For the interviews with the planners we did make a structured design, therefore after these interviews we were more certain we got all the information we needed. Next to this during the interviews and the survey we asked the respondents some questions that already indicated certain answers. For example in the survey we focused on the amount of work, because this aspect was mentioned a lot in earlier conversations. Amount of work was an important aspect according to the respondents, but the results might be different if we did not focus on this aspect that much.

Another discussion point is the way we evaluated the performance measures in Section 3.4. This evaluation was done by two people. A lot of measures needed to be evaluated based on multiple criteria. This makes it difficult to have a good overview. Therefore, the agreement was very small at first and the discussion consisted for a large part of explaining the measures and criteria. It would have been better to spend more time on evaluating the measures. Nevertheless, letting multiple people evaluate the performance measures was relevant, we believe that it improved the results.

## 8.3 Recommendations

In this section we describe our recommendations for Isala Klinieken. We give recommendations in three areas. The first subsection describes the main recommendations resulting from this research. During the project we were also involved in some other areas related to our research. Section 8.3.2 gives some recommendations based on this. Finally Section 8.3.3 discusses the possibilities for future research.

### 8.3.1 Recommendations from research

Based on our research we have four recommendations for Isala Klinieken. The first two are straightforward; we recommend Isala Klinieken to continue developing the proposed tool and to implement the tool like discussed in Chapter 7. It could eventually improve the processes at the wards, but first of all it helps recognize the problems in the interaction between the admissions schedule and the wards.

Our next recommendation is to change the focus within Isala Klinieken more to the wards. During the research it became clear that a lot of people in the organization recognize the need for insights for the admissions planners about the wards. This indicates that there are opportunities for this project in the organization. However, Isala Klinieken is just at the start of this process. One of the main barriers in this is that the OR department is seen as the most important resource. The admissions planners are judged based on the quality of their schedule for the OR. For the proposed tool to be effective this focus in the organization needs to change. It should become possible for the admissions planners to take into account the wards in their decisions.

Finally to be able to give admissions planners relevant insights in the processes at the wards it is most practical if the admissions for one ward are scheduled by one admissions planner or at least one team. In the current situation this is the case for a lot of wards, but in the new hospital the wards will be shared between specialisms. Also for wards that are used by almost all specialisms, like day care wards, it is important that there is some coordination in the scheduling of admissions.

### 8.3.2 Other recommendations

In the first chapter of this report we described the interaction between the admissions schedule and the wards on all hierarchical levels. In this research we focused on the operational offline level, but based on the description in the first chapter we can also give some recommendations about the other levels.

In Isala Klinieken a lot of information is available about the effects of the decisions for the ORs on the wards. We recommend to actually use this information for staff scheduling at the wards. On the strategic level there is information about production agreements, on the tactical level the tactical planning tool predicts the effects of the OR block schedule on the wards and on the operational level Isala Klinieken has the intensity of care tool.

During the interviews it became clear that between the OR block schedule and the admissions schedule there is another level in the organization, namely the schedule for the specialists. We recommend to also use this level to influence the processes at the wards and to give the wards more information for staff scheduling.

### 8.3.2 Future research

The first topic for future research is how to change the focus in Isala Klinieken from the OR department to the wards. In Section 8.3.1 we already mentioned this aspect. How this should be done is not known, more research is needed for this.

Secondly, future research is needed about insights in other resources than the wards. In this research we mainly focused on insights in the wards. However, admissions planners have to take into account more resources, like for example the IC, the ORs and the X-ray. During some of the interviews it was mentioned that the planners should also get insights into these other resources. The planner of the specialism Cardiology already takes into account all needed resources per admission. More research is necessary to find out whether it would result in improvements if this is done in the whole organization.

The third future research aspect is the correlation between the performance measures. In Chapter 3 we determined the performance measures that should be shown to the admissions planners. In this research we did not consider correlation between these measures because of two reasons. First, we don't know whether the correlation still exists if the planner uses the measures to change the schedule. Secondly, the correlation should also be recognized by the admissions planner. If the planner is convinced that the measures are independent, it is better to show them both. For these reasons it is better to look at correlation after the proposed tool is used for some time. After that it should be determined, together with the planner, if some performance measures can be removed.

For the proposed tool itself more research is needed to improve the input of the tool. The tool uses amongst other things the expected number of non-scheduled patients and a distribution for the length of stay as input. For the non-scheduled patients we now look at historical data about emergency patients. However, non-scheduled patients are not only emergency patients and the number also depends on the time until the admission day. The longer the remaining time until the admission day, the more patients will be added to the schedule. The distribution for the length of stay per treatment type is now determined based on historical data. However, some treatments only consist of a few patients per year. In that case this distribution is not reliable. Also we do not consider the expected length of stay indicated by the wards. This could give more information with more certainty about the length of stay. More research is needed to improve these two types of input of the tool. Most of the input needed for the tool is based on historical data. We also recommend linking the tool with the data warehouse, such that the input can continuously be adapted according to new historical data.

A final topic for future research is the way to integrate the performance measures into a rating for the total quality of a schedule. We described a method for this in Section 6.2. However, this method appears to be very dependent on amongst other things the ward and the length of the scheduling horizon. This makes it difficult to compare this number between wards and over time. More research is needed to make this rating for total quality more consistent.

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# Appendices

## Appendix A – OR block schedule

### Location Weezenlanden

| | OR1 | | OR2 | | OR4 | | OR5 | | OR6 | | OR7 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | M | A | M | A | M | A | M | A | M | A | M | A |
| Monday | ORT | ORT | ORT | ORT | URO | URO | ENT | ENT | ORT | ORT | JAW | JAW |
| Tuesday | ORT | ORT | ORT | ORT | URO | URO | ENT | ENT | ORT | ORT | JAW | JAW |
| Wednesday | ORT | ORT | ORT | ORT | URO | URO | ENT | ENT | URO | URO | JAW | JAW |
| Thursday | ORT | ORT | ORT | ORT | URO | URO | ENT | ENT | DS | DS | JAW | JAW |
| Friday | ORT | ORT | | | URO | URO | ENT | ENT | | | | |
| | | | | | | | | | | | | |
| Monday | ORT | ORT | ORT | ORT | URO | URO | ENT | ENT | ORT | ORT | URO | URO |
| Tuesday | ORT | ORT | ORT | ORT | URO | URO | ENT | ENT | ORT | ORT | JAW | JAW |
| Wednesday | ORT | ORT | ORT | ORT | URO | URO | ENT | ENT | ORT | ORT | URO | URO |
| Thursday | ORT | ORT | ORT | ORT | URO | URO | ENT | ENT | DS | DS | JAW | JAW |
| Friday | ORT | ORT | | | URO | URO | ENT | ENT | | | JAW | JAW |

| | OR8 | | OR9 | | OR10 | | OR11 | | Day care OR 1 | | Day care OR 2 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | M | A | M | A | M | A | M | A | M | A | M | A |
| Monday | GY | GY | THO | THO | THO | THO | THO | THO | DS | DS | OPH | OPH |
| Tuesday | THO | THO | THO | THO | THO | THO | THO | THO | ORT | OPH | ORT | OPH |
| Wednesday | THO | THO | THO | THO | THO | THO | THO | THO | OPH | OPH | OPH | OPH |
| Thursday | THO | THO | THO | THO | THO | THO | THO | THO | ORT | ORT | OPH | OPH |
| Friday | | | THO | THO | THO | THO | THO | THO | OPH | ORT | OPH | ORT |
| | | | | | | | | | | | | |
| Monday | GY | GY | THO | THO | THO | THO | THO | THO | DS | DS | OPH | OPH |
| Tuesday | THO | THO | THO | THO | THO | THO | THO | THO | ORT | OPH | ORT | OPH |
| Wednesday | THO | THO | THO | THO | THO | THO | THO | THO | OPH | OPH | OPH | OPH |
| Thursday | THO | THO | THO | THO | THO | THO | THO | THO | ORT | ORT | OPH | OPH |
| Friday | | | THO | THO | THO | THO | THO | THO | OPH | ORT | OPH | ORT |

**Legend**

| | |
|---|---|
| GY | Gynecology |
| JAW | Jaw surgery |
| ENT | Ear, nose and throat surgery |
| DS | Special dental surgery |
| ORT | Orthopedics |
| THO | Thoracic surgery |
| URO | Urology |
| OPH | Ophthalmology |
| | Empty/flexible slots |

**Location Sophia**

| | OR1 | | OR2 | | OR3 | | OR4 | | OR5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | M | A | M | A | M | A | M | A | M | A |
| Monday | NE | NE | GS | GS | EM | EM | GS | GS | NE | NE |
| Tuesday | GS | GS | GS | GS | EM | EM | GS | GS | NE | NE |
| Wednesday | GS | GS | GS | GS | EM | EM | GS | GS | NE | NE |
| Thursday | NE | NE | GS | GS | EM | EM | GS | GS | NE | NE |
| Friday | NE | NE | GS | GS | EM | EM | GS | GS | NE | NE |

| | OR6 | | OR7 | | OR8 | | Day care OR 1 | | Day care OR 2 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | M | A | M | A | M | A | M | A | M | A |
| Monday | GS | GS | GY | GY | PS | PS | GS | GS | GS | GS |
| Tuesday | GY | GY | GY | GY | PS | PS | PS | PS | GS | GS |
| Wednesday | PS | PS | GY | GY | PS | PS | ENT | ENT | ENT | ENT |
| Thursday | GS | GS | GY | GY | GS | GS | GY | GY | GS | GS |
| Friday | PS | GY | GY | GY | PS | PS | PS/ENT | PS/MRI | PS/ENT | PS/MRI |

**Legend**

| | |
|---|---|
| EM | Emergency OR |
| GS | General surgery |
| GY | Gynecology |
| NE | Neurosurgery |
| PS | Plastic surgery |
| ENT | Ear, nose and throat surgery |
| | Empty/flexible slots |

## Appendix B – Interview design tactical level

At the beginning of the interview we gave a short introduction into the research and the goal of the interview. After that the following questions were asked:

1) What is, after listening to this explanation, you first idea about this research? And what could you contribute to it?

2) What are the tasks and decisions for the wards in which you are involved?

3) What are the tasks and decisions for the admissions schedules in which you are involved?

4) On which aspects do you judge the wards?

5) In literature a distinction is made between financial performance and quality performance, and between internal and external performance (see table below with examples). Considering this framework, are there any other aspects on which you judge the wards?

| | Financial | Quality |
|---|---|---|
| **Internal** | Utilization | Level bed utilization |
| **External** | Liquidity | Cancellations |

6) What would be the ideal situation for the ward from your point of view?

7) What should the admissions planners take into account when scheduling the admissions?

8) Which information should they see for this?

9) Does your specialism share wards with other specialisms? (only for managers of specialisms)

    a) How does the interaction go?

    b) What role should the tool play in this interaction between specialisms?

10) In the new hospital some things will change, also for the wards. Are there aspects that we should take into account when developing the tool to make sure the tool is also useful in the new hospital?

11) What should be the results after implementing the tool (the final goal)?

12) Are there aspects which are not yet discussed, but which are important to take into account during this research?

## Appendix C – Interview design operational level

At the beginning of the interview we gave a short introduction into the research and the goal of the interview. After that the following questions were asked:

1) What is, after listening to this explanation, you first idea about this research? And what could you contribute to it?

2) What are the tasks and decisions for the wards in which you are involved?

3) Which aspects are important for a good admissions schedule for the wards?

4) In literature a distinction is made between financial performance and quality performance, and between internal and external performance (see table below with examples). Considering this framework, are there any other aspects on which you judge the wards?

| | Financial | Quality |
|---|---|---|
| Internal | Utilization | Level bed utilization |
| External | Liquidity | Cancellations |

5) What would be the ideal situation for the ward from your point of view?

6) What should the admissions planners take into account when scheduling the admissions?

7) Which information should they see for this?

8) Is there a pattern in when emergencies arrive (during the day and during the week) for some wards? And is this different per ward?

9) What determines the amount of work on a ward?

10) What would be the best way to determine intensity of care?

11) Should the amount of work be leveled over the week?

12) Should the amount of work be leveled during the day?

13) In the new hospital some things will change, also for the wards. Are there aspects that we should take into account when developing the tool to make sure the tool is also useful in the new hospital?

14) What should be the results after implementing the tool (the final goal)?

15) Are there aspects which are not yet discussed, but which are important to take into account during this research?

## Appendix D – Survey questions

For my study Industrial Engineering and Management I perform a research project for the department Patient Logistics of Isala Klinieken (my supervisor is Bernd van den Akker). The research is about the effects of an admissions schedule on the wards.

An admissions planner schedules the admissions for a specialism while looking especially at the treatments (for example the OR). The wards adapt to this schedule. The number of (scheduled) patients on a ward differs a lot. A reason for this is that admissions planners at this moment do not have insights into the effects of their schedule on the wards, let alone that they could take it into account. The goal of my research is to change this.

The first question in this is: which insights should the admissions planners have to be able to take the wards into account? This especially depends on what you as staff of the wards think is a good schedule. By filling out this survey you can help me in this.

Thank you very much for your cooperation and good luck in completing the survey!

Sincerely,

Annemaaike Hooijsma (a.hooijsma@isala.nl)

**General**

At which ward do you work (multiple answers possible)?

- ○ SZ-A1
- ○ …
- ○ WL-B6
- ○ Other namely: __________

For which specialism do you work at this ward (multiple answers possible)?

- ○ Anesthesiology
- ○ …
- ○ Urology
- ○ Other namely: __________

Is this ward <u>only</u> meant for day care patients?

- ○ Yes
- ○ No

**Schedule previous week**

If you think back to the previous week, on which days did you think the admissions schedule was good (multiple answers possible)? And why was the schedule on these days good?

- ○ Monday
- ○ …
- ○ Sunday
- ○ There was no day with a good schedule

Reasons (at the next question you can explain the days with a poor schedule):

On which day did you think the admissions schedule was not good (multiple answers possible)? And why?

- ○ Monday
- ○ …
- ○ Sunday
- ○ There was not day with a poor schedule

Reasons:

**Important aspects**

Below a list is displayed of aspects that could be important for a good schedule for a ward (when looking at scheduled admissions). Could you indicate per aspect how important this is for your ward? Not all aspects will be completely feasible, but the admissions planner could take it into account, what makes at least an improvement possible.

| | Not at all important | Not important | Neutral | Important | Very important |
|---|---|---|---|---|---|
| Sufficient beds for the scheduled patients | ○ | ○ | ○ | ○ | ○ |
| Sufficient beds reserved for emergencies | ○ | ○ | ○ | ○ | ○ |
| The patients (from your specialism) on the right ward | ○ | ○ | ○ | ○ | ○ |
| A constant amount of work during the day | ○ | ○ | ○ | ○ | ○ |
| The same amount of work on different days | ○ | ○ | ○ | ○ | ○ |
| A predictable amount of work | ○ | ○ | ○ | ○ | ○ |

Mention at least one other aspect that is important for a good admissions schedule looking from the perspective of a nurse.

Mention at least one other aspect that is important for a good admissions schedule looking from the perspective of the patient.

Most wards in Isala Klinieken have a KPI dashboard and/or a day board. On these board amongst other things indicators are displayed which the ward uses for control. Are on the dashboard and/or day board of your ward indicators displayed which should also be known by the admissions planner, such that he/she can take them into account when scheduling the admissions? If yes, what are these indicators?

- ○ No
- ○ Yes, namely:

**Emergencies**

Indicate if the following statements are true or false.

A pattern is recognizable in when emergencies arrive during the day. So on certain moments of a day often a lot of emergencies arrive.

- ○ True
- ○ False

A pattern is recognizable in when emergencies arrive during the week.

- ○ True
- ○ False

**Amount of work**

In previous questions amount of work is already mentioned a few times. However, what is amount of work on a ward exactly?

Make a choice between the following two statements:

- ○ The number of used beds says enough about the amount of work
- ○ Also the intensity of care of the patients in the beds is important for determining the amount of work

If we want to determine the amount of work based on the intensity of care of the patients, there has to be a way to determine this intensity of care. Of course the intensity of care will differ per patient and per nurse, but it is important to give an estimation of it. The next questions are about this.

Make a choice between the following three statements:

- ○ Intensity of care of a patient is almost constant, so one number for the intensity of care per patient is sufficient
- ○ It should be possible to indicate the intensity of care of a patient per day
- ○ It should be possible to indicate the intensity of care of a patient per hour

Indicate if the following statement is true or false:

The intensity of care of a patient also depends on the treatment phase (for example just before or after a surgery)

- ○ True
- ○ False

Make a choice between the following two statements:

- ○ Intensity of care based on the type of treatment gives a good indication
- ○ Intensity of care differs a lot per patient while the treatment might be the same. So the intensity of care should be based on patient characteristics.

*(only visible if on the previous question the second answer was given)* You mention that intensity of care should be based on patient characteristics. Which patient characteristics, that are known in advance, give enough information of intensity of care (multiple answers possible)?

- ○ ASA classification (determined by the anesthetist)
- ○ ADL scale (activities of daily living scale)
- ○ Other namely: __________

Next to (intensity of care of) the patients that are present at the ward, there might also be some other aspects that lead to amount of work. Indicate whether the following aspects lead to that much amount of work that the admissions planners should have insights in it (multiple answers possible).

- ○ Number of admissions
- ○ Number of discharges
- ○ Other namely: __________

Indicate whether the following statement is true or false:

> If on a certain day the number of discharges and admissions is small, it is not a problem if there are a lot of patients at the ward.

- ○ True
- ○ False

Is it possible to compare the different aspects of amount of work? For example, a discharge on average takes twice as much time as an admission. Or a discharge takes on average three times as much time as an 'average' patient that you have to care for during a day.

- ○ Yes
- ○ No

**Amount of work on different days**

The following questions are about a constant amount of work on different days, so for example on Tuesday there is the same amount of work as on Monday. Whether the amount of work should also be equally distributed over the day, will be discussed later. When answering these questions, assume that amount of work will be measured like you indicated during the previous questions.

Make a choice between the following statements:

- ○ It would be ideal if the amount of work would be equal for all (week)days
- ○ Amount of work doesn't have to be equal for all days, as long as there is constant pattern in the amount of work during the week (so on Monday always the same amount of work as on other Mondays etc.)
- ○ Amount of work doesn't have to be equal for all days or according to constant pattern.

*(only visible for non-day care wards and if on the previous question the first answer was given)* You indicate that the amount of work should be equal on different days, but which days do you mean?

- ○ Amount of work should be constant on weekdays, but not on weekend days
- ○ Amount of work should be constant on both weekdays and weekend days. However, it is not a problem if amount of work is smaller during the weekend.
- ○ Amount of work should be constant for all days (so during the weekend the same amount of work as on weekdays)

*(only visible for non-day care wards and if on the first question of this subsection the first or second answer was given)* Imagine, during a week at 0:00 there is always the same number of patients (with the same intensity of care) on your ward, next to that every day has the same number of admissions and discharges. Would this mean that the amount of work is equal for all days? If not, why?

- ○ Yes
- ○ No, because

**Amount of work during the day**

Previous questioned discussed a constant amount of work on different days. This does not mean that the amount of work is also equally distributed over the day. The next question will deal with that.

Make a choice between the next three statements:

- ○ Amount of work should also be constant during the day.
- ○ Amount of work does not have to be constant during the day, as long as it follows a constant pattern (for example always a high amount of work between 10 and 11 am)
- ○ It is not necessary that the admissions planner tries to get the amount of work constant or according to a constant pattern during the day, this will go automatically.

*(only visible for non-day care wards and if on the previous question the first or second answer was given)* Make a choice between the following two statements:

- ○ Amount of work should be constant during daytime (for example between 8:00 and 17:00), but it is not a problem if it is smaller during the night.
- ○ Amount of work should be constant during the whole day (24 hours)

*(only visible for non-day care wards and if on the first question of this subsection the first answer was given)* Make a choice between the following two statements:

- ○ A constant amount of work during the day is only necessary for weekdays
- ○ A constant amount of work during the day is necessary for all days

*(only visible for non-day care wards and if on the first question of this subsection the second answer was given)* Make a choice between the following two statements:

- ○ A constant pattern for the amount of work during the day is only necessary for weekdays
- ○ A constant pattern for the amount of work during the day is necessary for all days

**Other comments**

Are there any aspects that were not mentioned in this survey, but which are important to consider during this research?

Thank you for completing this survey!

You can close the survey by pressing the button 'Send'.

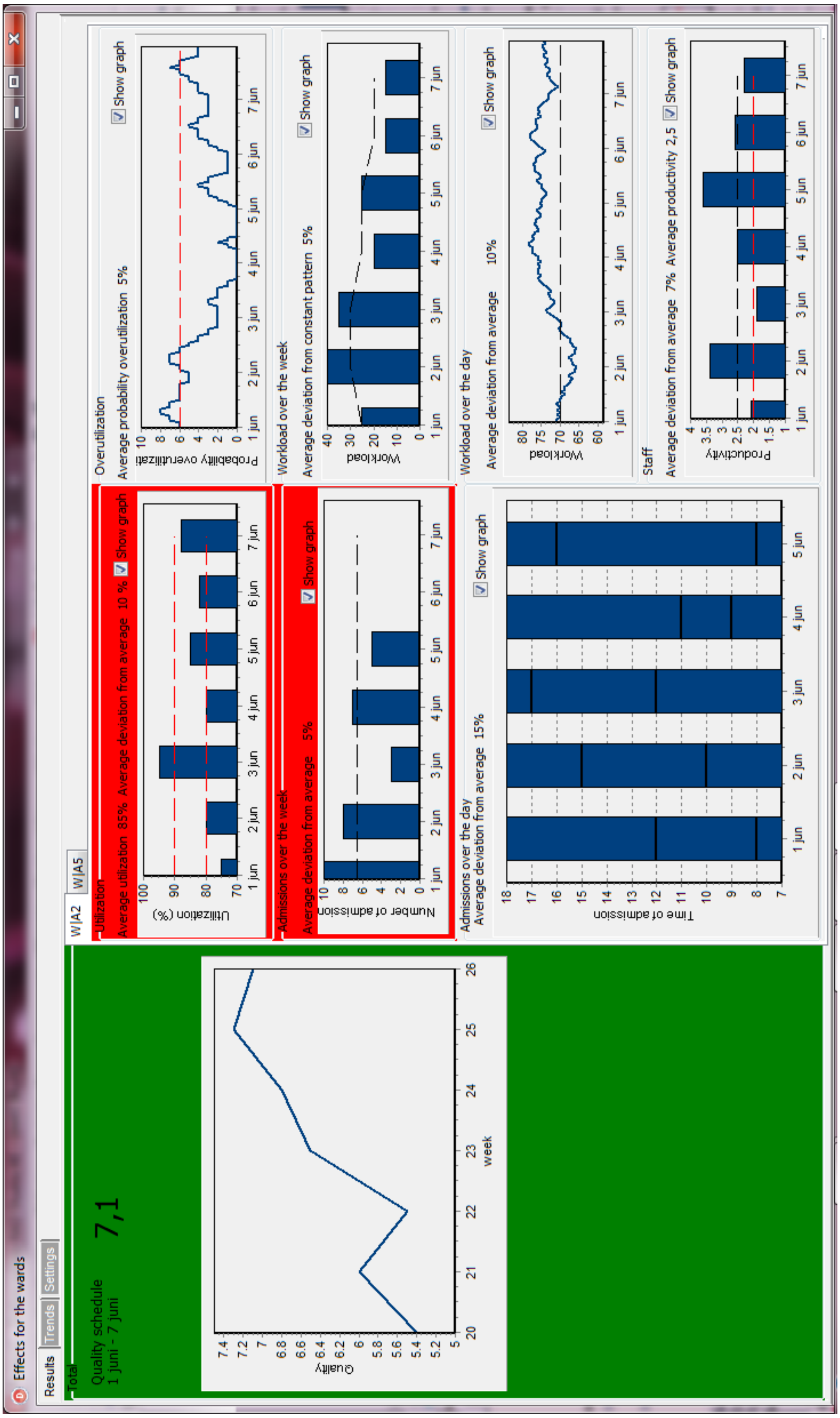
If you have any questions or comments, please let me know (a.hooijsma@isala.nl).

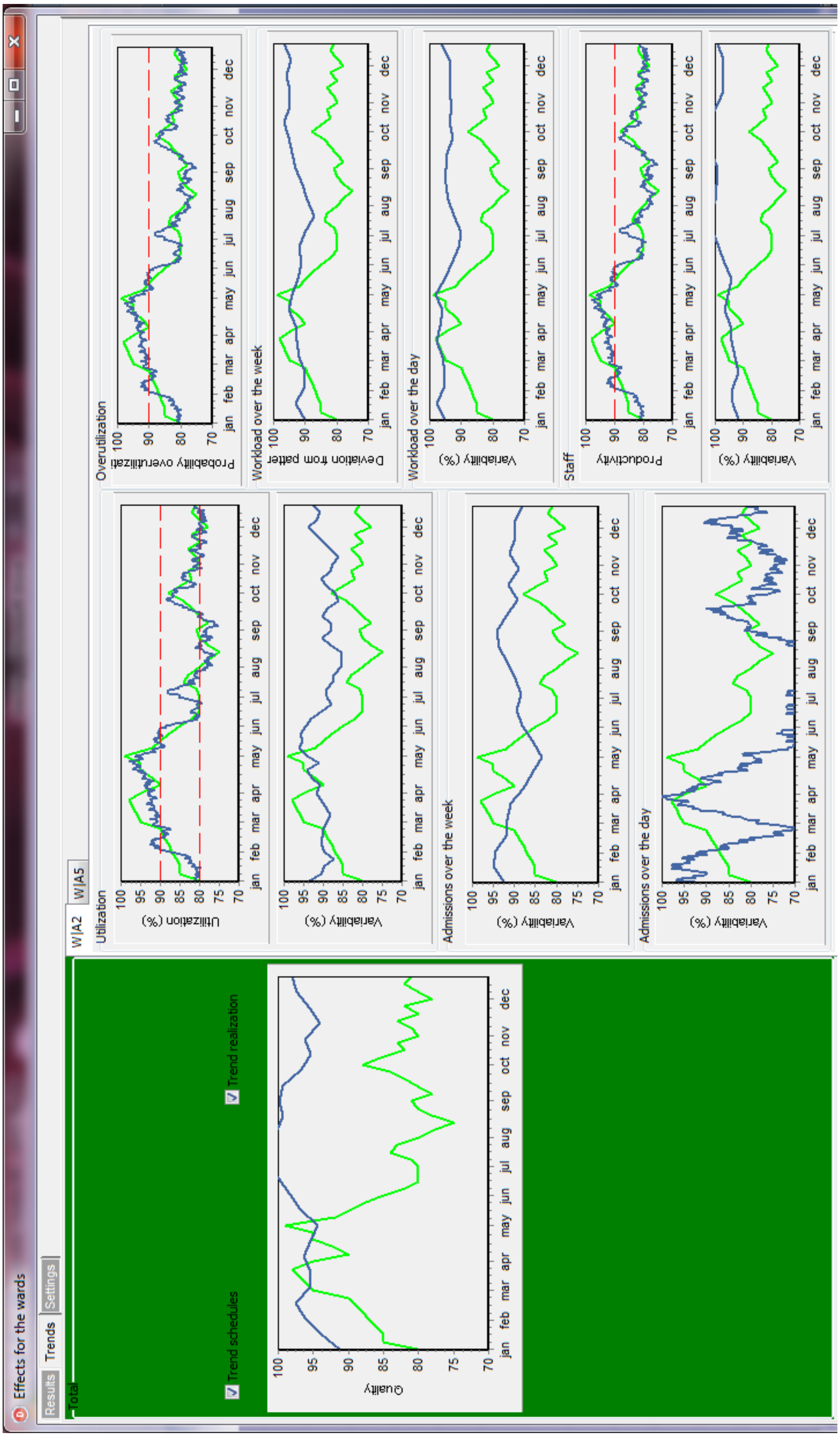
## Appendix E – Interview design admissions planners

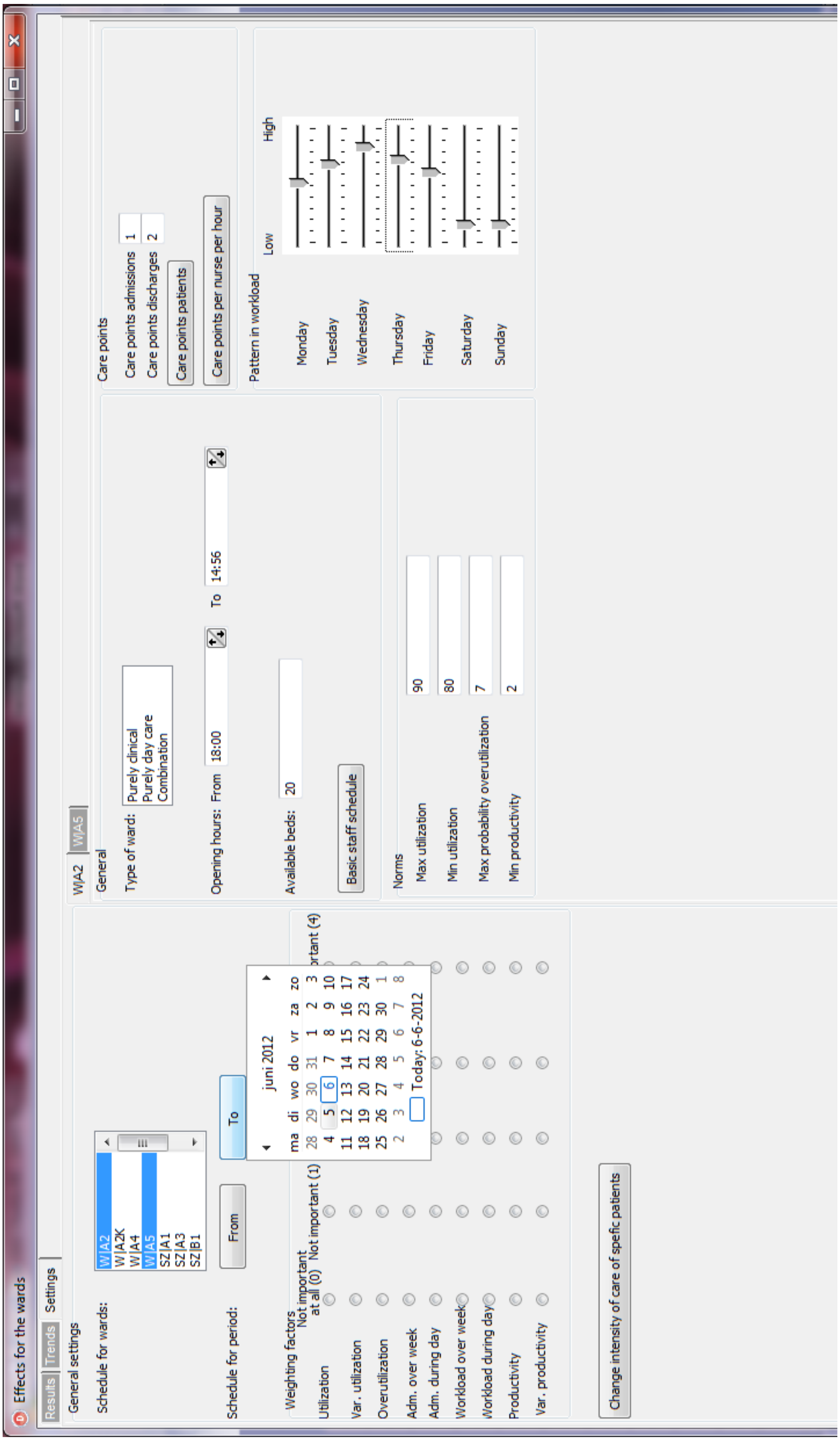
At the beginning of the interview we gave a short introduction into the research and the goal of the interview. Also we introduced the performance indicators mentioned during the previous interviews and survey. After that the following questions were asked:

1. Could you shortly explain how you make an admissions schedule?
2. How far ahead do you make the schedule?
3. Does the schedule change a lot after it is ready, for example because of emergencies?
4. What is, after listening to this explanation, your first idea about this research?
5. Which aspects of the wards do you already see in the current scheduling program?
6. Do you also consider these aspects when making the schedule?
7. Which aspects about the wards would you prefer to see next to the ones already mentioned?
8. If all the performance measures that are mentioned would be shown in the tool, it could become very unclear. Only those measures which are really useful for you as a planner should be displayed. Could you rank the mentioned performance measures based on their importance?
9. Should the tool be combined with the current scheduling program? And how?
10. At which moment in the scheduling process should the tool be used?
11. Imagine that you open the tool, what would you want to see? How would it look like on the screen?
12. How should the performance measures be presented?
13. Should the tool also give norms?
14. Should the tool also give the performance of previous periods?
15. Do you schedule admissions for multiple wards? If yes, how should the tool display this?
16. Do other specialisms also schedule for the wards for which you schedule?
    a. How is this interaction going now?
    b. In the new hospital this will happen even more because of the larger wards. How should this be arranged? Imagine you are making the schedule before another specialism, how could you take this other specialism into account?
17. Are there aspects which are not yet discussed, but which are important to take into account during this research?

# Appendix F – Conceptual model




Effects for the wards
Results
Trends
Settings
Total
Trend schedules
Trend realization
Quality
W|A2
W|A5
Utilization
Utilization (%)
Variability (%)
Admissions over the week
Admissions over the day
Overutilization
Probability overutilizati
Workload over the week
Deviation from patter
Workload over the day
Staff
Productivity



Effects for the wards
Results
Trends
Settings
General settings
Schedule for wards:
W|A2
W|A2K
W|A4
W|A5
SZ|A1
SZ|A3
SZ|B1
Schedule for period:
From
To
juni 2012
ma di wo do vr za zo
Today: 6-6-2012
Weighting factors
Not important at all (0)
Not important (1)
Important (4)
Utilization
Var. utilization
Overutilization
Adm. over week
Adm. during day
Workload over week
Workload during day
Productivity
Var. productivity
Change intensity of care of spefic patients
WA2
WA5
General
Type of ward:
Purely clinical
Purely day care
Combination
Opening hours: From
18:00
To
14:56
Available beds:
20
Basic staff schedule
Norms
Max utilization
90
Min utilization
80
Max probability overutilization
7
Min productivity
2
Care points
Care points admissions
1
Care points discharges
2
Care points patients
Care points per nurse per hour
Pattern in workload
Low
High
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday

## Appendix G – Overview variables forecasts

Variables

| | |
|---|---|
| $a_m^w$ | Number of admissions at ward w at day m |
| $a_{m,t}^w$ | Number of admissions at ward w at day m during time slot t |
| $a_{m,t}^{w,j}$ | Number of admissions of treatment type j at ward w at day m during time slot t |
| $sa_{m,t}^w$ | Number of scheduled admissions at ward w at day m during time slot t |
| $sa_{-1}^w$ | Number of patients present at ward w at the moment of calculation |
| $sa_q^w$ | Number of scheduled admissions at ward w at day q |
| $nsa_r^w$ | Number of non-scheduled admissions at ward w at weekday r |
| $perca_t^w$ | Percentage of all admissions during a day at ward w that take place during time slot t |
| $d_m^w$ | Number of clinical discharges at ward w at day m |
| $d_{m,t}^w$ | Number of clinical discharges at ward w at day m during time slot t |
| $d_{m,t}^{w,j,v}$ | Number of discharges of clinical patients of treatment type j who are already v days in the hospital, at ward w at day m during time slot t |
| $sd_m^w$ | Number of discharges of scheduled clinical patients at ward w at day m |
| $sd_m^{w,q}$ | Number of discharges of scheduled clinical patients who are admitted at day q at ward w at day m |
| $nsd_m^w$ | Number of discharges of non-scheduled clinical patients at ward w at day m |
| $nsd_m^{w,q}$ | Number of discharges of non-scheduled clinical patients who arrived at day q at ward w at day m |
| $percd_t^w$ | Percentage of all clinical discharges during a day at ward w that take place during time slot t |
| $\mathrm{P}^{w,q}(n)$ | Probability that the length of stay of clinical patients that are admitted at day q on ward w is n days |
| $O^j(n)$ | Probability that the length of stay of patients of treatment type j is n days |
| $O^{w,ns}(n)$ | Probability that the length of stay of non-scheduled clinical patients at ward w is n days |
| $u^{w,q,j}$ | Number of scheduled clinical patients of treatment type j who are admitted at day q at ward w |
| $u_v^{w,-1,j}$ | Number of clinical patients of treatment type j who are already present at ward w and have been in the hospital for v days |
| $b_{m,t}^w$ | Number of used beds by clinical patients at ward w at day m during time slot t |
| $b_{m,t}^{w,j,v}$ | Number of used beds by clinical patients of type j who are already v days in the hospital, at ward w at day m during time slot t |
| $T_{m,t}^w$ | Distribution for the total number of patients on ward w on day m at the beginning of time slot t |
| $Z_{m,t}^w$ | Distribution for the total number of clinical patients on ward w on day m at the beginning of time slot t |
| $H_{m,t}^w$ | Distribution for the number of scheduled clinical patients on ward w on day m at the beginning of time slot t |

| | |
|---|---|
| $\bar{h}_{m,t}^{w,q}$ | Distribution for the number of scheduled clinical patients who are admitted at day q and who utilize a bed on ward w at day m at the beginning of time slot t |
| $h_{n,t}^{w,q}$ | Distribution for the number of scheduled clinical patients who are admitted at day q and who utilize a bed on ward w at the beginning of time slot t n days after being admitted |
| $h_{n}^{w,q}$ | Distribution for the number of scheduled clinical patients who are admitted at day q and who utilize a bed on ward w n days after being admitted at the beginning of the day |
| $p_{n,t}^{w,q}$ | Probability that a scheduled clinical patient who is admitted at day q on ward w and utilizes a bed at the beginning of time slot t n days after being admitted, will be discharged during that time slot |
| $p_{n}^{w,q}$ | Probability that a scheduled clinical patient, who is admitted at day q on ward w and utilizes a bed at the beginning of the day n days after being admitted, will be discharged that day |
| $G_{m,t}^{w}$ | Distribution for the number of non-scheduled clinical patients on ward w on day m at the beginning of time slot t |
| $\bar{g}_{m,t}^{w,q}$ | Distribution for number of non-scheduled clinical patients who are admitted at day q and who utilize a bed on ward w at day m at the beginning of time slot t |
| $g_{n,t}^{w,r}$ | Distribution for number of non-scheduled clinical patients who arrive at weekday r and who utilize a bed on ward w at the beginning of time slot t n days after being admitted |
| $g_{n}^{w,r}$ | Distribution for number of non-scheduled clinical patients who arrive at weekday r and who utilize a bed on ward w n days after being admitted at the beginning of the day |
| $o_{n,t}^{w}$ | Probability that a non-scheduled clinical patient, who utilizes a bed on ward w at the beginning of time slot t n days after being admitted, will be discharged during that time slot |
| $o_{n}^{w}$ | Probability that a non-scheduled clinical patient, who utilizes a bed on ward w at the beginning of the day n days after being admitted, will be discharged that day |
| $d'^{w}_{m}$ | Number of day care discharges at ward w at day m |
| $d'^{w}_{m,t}$ | Number of day care discharges at ward w at day m during time slot t |
| $d'^{w,j}_{m,t}$ | Number of discharges of day care patients of treatment type j at ward w at day m during time slot t |
| $sd'^{w}_{m,t}$ | Number of discharges of scheduled day care patients at ward w at day m during time slot t |
| $sd'^{w,o}_{m,t}$ | Number of discharges of scheduled day care patients who are admitted during time slot o at ward w at day m during time slot t |
| $nsd'^{w}_{m,t}$ | Number of discharges of non-scheduled day care patients at w at day m during time slot t |
| $nsd'^{w,o}_{m,t}$ | Number of discharges of non-scheduled day care patients who arrived during time slot o at ward w at day m during time slot t |
| $\mathrm{P}'^{w,o}_{m}(n)$ | Probability that the length of stay of day care patients that are admitted during time slot o of day m on ward w is n hours |

| | |
|---|---|
| $O'^{j}(n)$ | Probability that the length of stay of day care patients of treatment type j is n hours |
| $O'^{w,ns}(n)$ | Probability that the length of stay of non-scheduled day care patients at ward w is x hours |
| $u'^{w,o,j}_{m}$ | Number of scheduled day care patients of treatment type j who are admitted during time slot o of day m at ward w |
| $b'^{w}_{m,t}$ | Number of used beds by day care patients at ward w at day m during time slot t |
| $b'^{w,j}_{m,t}$ | Number of used beds by day care patients of type j at ward w at day m during time slot t |
| $Z'^{w}_{m,t}$ | Distribution for the total number of day care patients on ward w on day m at the beginning of time slot t |
| $H'^{w}_{m,t}$ | Distribution for the number of scheduled day care patients on ward w on day m at the beginning of time slot t |
| $\bar{h}'^{w,o}_{m,t}$ | Distribution for the number of scheduled day care patients who are admitted during time slot o and who utilize a bed on ward w at day m at the beginning of time slot t |
| $h'^{w,o}_{m,n}$ | Distribution for the number of scheduled day care patients who are admitted during time slot o and who utilize a bed on ward w at day m n timeslots after being admitted |
| $p'^{w,o}_{m,n}$ | Probability that a scheduled day care patient who is admitted during time slot o on ward w and utilizes a bed at day m n time slots after being admitted, will be discharged during that time slot |
| $G'^{w}_{m,t}$ | Distribution for the number of non-scheduled day care patients on ward w on day m at the beginning of time slot t |
| $\bar{g}'^{w,o}_{m,t}$ | Distribution for number of non-scheduled day care patients who are admitted during time slot o and who utilize a bed on ward w at day m at the beginning of time slot t |
| $g'^{w,o}_{r,n}$ | Distribution for number of non-scheduled day care patients who arrive during time slot o of weekday r and who utilize a bed on ward w n time slots after being admitted |
| $o'^{w}_{r,n}$ | Probability that a non-scheduled day care patient, who utilizes a bed on ward w at weekday r n time slots after being admitted, will be discharged during that time slot |

Parameters

| | |
|---|---|
| $m$ | Day |
| $r$ | Weekday |
| $n$ | Number of days after being admitted |
| $t$ | Timeslot |
| $w$ | Ward |
| $o$ | Admission time slot |
| $q$ | Admission day |
| $j$ | Treatment type, reason for admission |
| $v$ | Number of days already in the hospital |
| $x$ | Number of patients |

Constants

| | |
|---|---|
| $Q$ | Last day of the scheduling horizon |
| $R$ | Number of weekdays, 7 days |
| $T$ | Number of time slot, 24 hours |

| | |
|---|---|
| $J^{w}$ | Number of treatment types on ward w |
| $L^{w,q}$ | Maximum length of stay of patients admitted at day q at ward w |
| $L^{w,-1}$ | Maximum length of stay of patients already present at ward w |
| $L^{w,ns}$ | Maximum length of stay of non-scheduled patients ward w |
| $L_{m}^{w,o}$ | Maximum length of stay of patients admitted during time slot o of day m at ward w |
| $T^{-1}$ | Moment of calculation |

# Appendix I – Explanation distribution of the number of used beds per hour

Explanation calculations in Figure 6.1

The basic idea is that the distribution for the total number of patients on ward w on day m at the beginning of time slot t, $T^{w}_{m,t}$, can be determined by adding the distributions for the clinical patients, $Z^{w}_{m,t}$, and the day care patients, $Z'^{w}_{m,t}$.

$$T^{w}_{m,t} = Z^{w}_{m,t} * Z'^{w}_{m,t} \qquad \text{for m=0,…,Q; t=0,..,T-1; } \forall \text{ w}$$

The distribution for the number of clinical patients, $Z^{w}_{m,t}$, can be determined by adding the distributions for the scheduled patients, $H^{w}_{m,t}$, and the non-scheduled patients, $G^{w}_{m,t}$.

$$Z^{w}_{m,t} = H^{w}_{m,t} * G^{w}_{m,t} \qquad \text{for m=0,…,Q; t=0,..,T-1; } \forall \text{ w}$$

The distribution for the scheduled patients, $H^{w}_{m,t}$, can be calculated by adding the different distributions for patients that are admitted on different days, $\overline{h}^{w,q}_{m,t}$. In this q is the admission day of a patient and q = -1 includes the patients that are already present at the ward. In the model of Smeenk (2011) there are no patients that are already present.

$$H^{w}_{m,t} = \overline{h}^{w,-1}_{m,t} * \overline{h}^{w,0}_{m,t} * \overline{h}^{w,1}_{m,t} * \ldots * \overline{h}^{w,m}_{m,t} \qquad \text{for m=0,…,Q; t=0,…,T-1; } \forall \text{ w}$$

The distribution for the non-scheduled patients, $G^{w}_{m,t}$, can also be calculated by adding the distributions for the patient groups that arrived at different days. In the model of Smeenk (2011) this formula includes distributions for all weekdays, because the next step in that model is to calculate a steady state. That is not the case here, so we use distributions for all days in the scheduling horizon.

$$G^{w}_{m,t} = \overline{g}^{w,0}_{m,t} * \overline{g}^{w,1}_{m,t} * \ldots * \overline{g}^{w,m}_{m,t} \qquad \text{for m=0,…,Q; t=0,…,T-1; } \forall \text{ w}$$

For the day care patients we use the same structure in the calculations as for the clinical patients. The difference is that we here use time slots where we used days for the clinical patients. For the clinical patients these days are divided into timeslots, here we do not divide the timeslots into smaller parts. For the day care patients we do not calculate the distributions for the day of calculation and therefore there are no patients present at the moment of calculation. Despite of these differences, the structure is the same as for the clinical patients. Therefore we do not discuss the formulas in detail. The formulas are displayed below. In this o is the admission time slot, m is the day in the scheduling horizon, t is the time slot and n is the number of timeslots after admission.

$$Z'^{w}_{m,t} = H'^{w}_{m,t} * G'^{w}_{m,t} \qquad \text{for m=1,…,Q; t=0,…,T-1; } \forall \text{ w}$$

$$H'^{w}_{m,t} = \overline{h}'^{w,0}_{m,t} * \overline{h}'^{w,1}_{m,t} * \ldots * \overline{h}'^{w,t}_{m,t} \qquad \text{for m=1,…,Q; t=0,…,T-1; } \forall \text{ w}$$

$$G'^{w}_{m,t} = \overline{g}'^{w,0}_{m,t} * \overline{g}'^{w,1}_{m,t} * \ldots * \overline{g}'^{w,t}_{m,t} \qquad \text{for m=1,…,Q; t=0,…,T-1; } \forall \text{ w}$$

Calculations for groups of scheduled clinical patients

To make the calculations easier we rewrite the distributions for the different admission days. In the formula for $H_{m,t}^{w}$ we use a distribution for day m, $\bar{h}_{m,t}^{w,q}$. We now rewrite this into a distribution for n days after the patients are admitted, $h_{n,t}^{w,q}(x)$, where x is the number of patients. So the distribution for day m for patients admitted at day q, will now become a distribution for n=m-q days after admission.

$$\bar{h}_{m,t}^{w,q}(x) = \begin{cases} 1 & m < q, x = 0 \\ 0 & m < q, x > 0 \\ h_{m-q,t}^{w,q} & m \geq q \end{cases} \qquad \text{for m=0,...,Q; t=0,...,T-1; q=-1,...,Q; } \forall \text{ w}$$

*1. Distribution for the first day, patients already present*

At the moment of calculation, $T^{-1}$, already some patients are in the ward, these patients can be discharged during that day. At the moment of calculation we know the present number of patients at ward w, $sa_{-1}^{w}$. During the rest of the day every patient has a probability $p_{0,t}^{w,-1}$ to be discharged during a certain timeslot and a probability $1 - p_{0,t}^{w,-1}$ of staying. If there are k patients at the ward, the probability of x patients at the ward during the next period can be calculated using a binomial distribution, $\binom{k}{x}(p_{0,t}^{w,-1})^{k-x}(1-p_{0,t}^{w,-1})^{x}$. We know the distribution for the number of patients at the ward during the previous timeslot. We can use this distribution together with the binomial formula to calculate the distribution for the number of patients at the ward during this timeslot.

$$h_{0,t}^{w,-1}(x) = \begin{cases} 1 & t \leq T^{-1}, x = sa_{-1}^{w} \\ 0 & t \leq T^{-1}, x \neq sa_{-1}^{w} \\ \sum_{k=x}^{sa_{-1}^{w}} \binom{k}{x} (p_{0,t-1}^{w,-1})^{k-x}(1-p_{0,t-1}^{w,-1})^{x} h_{0,t-1}^{w,-1}(k) & t > T^{-1} \end{cases} \qquad \text{for t=0,...,T-1; } \forall \text{ w}$$

*2. Distribution for the day of admission, patients not yet admitted*

We assume that clinical patients will not be discharged on the day of admission. So the number of patients which were not present yet is known with certainty on the day of admission, n=0. This admissions process differs from that in the model of Smeenk (2011), because in our situation there is certainty about the number of scheduled patients. Another difference is that Smeenk (2011) differentiates between patients that are admitted on the day of surgery and patients that are admitted the day before; we do not make that distinction.

$$h_{0,t}^{w,q}(x) = \begin{cases} 1 & x = \sum_{k=0}^{t-1} sa_{q,k}^{w} \\ 0 & x \neq \sum_{k=0}^{t-1} sa_{q,k}^{w} \end{cases} \qquad \text{for t=0,...,T-1; q=0,...,Q; } \forall \text{ w}$$

*3. Distribution for the other days*

*3.1. Distribution for the beginning of the day*

We first calculate the number of patients at the beginning of the day, $h_n^{w,q}$. This way of reasoning is similar to that in the model of Smeenk (2011). For patients not yet present this number is known with certainty for the first day after admission (step 3.1.2), because on the day of admission no patients were discharged. For the next days and for patients already present (step 3.1.1 and 3.1.3) we calculate it using a binomial distribution, using a probability that a patient is discharged at a certain day, $p_n^{w,q}$.

$$h_n^{w,q}(x) = \begin{cases} 1 & n=1, x = sa_q^w, q \geq 0 \\ 0 & n=1, x \neq sa_q^w, q \geq 0 \\ \sum_{k=x}^{sa_{-1}^w} \binom{k}{x} (p_{0,T-1}^{w,q})^{k-x} (1-p_{0,T-1}^{w,q})^x h_{0,T-1}^{w,q}(k) & n=1, q=-1 \\ \sum_{k=x}^{sa_q^w} \binom{k}{x} (p_{n-1}^{w,q})^{k-x} (1-p_{n-1}^{w,q})^x h_{n-1}^{w,q}(k) & n=2,\ldots,Q-q \end{cases}$$

for n=1,…,Q-q; q=-1,…,Q; $\forall$ w

*3.2. Distribution for the rest of the day*

We use the distribution for the number of patients at the beginning of the day as a starting point for the distributions for the rest of the day, $h_{n,t}^{w,q}$. Here again we use a binomial distribution.

$$h_{n,t}^{w,q}(x) = \begin{cases} h_n^{w,q}(x) & t=0 \\ \sum_{k=x}^{sa_q^w} \binom{k}{x} (p_{n,t-1}^{w,q})^{k-x} (1-p_{n,t-1}^{w,q})^x h_{n,t-1}^{w,q}(k) & t=1,\ldots,T-1 \end{cases}$$

for n=1,…,Q-q; t=0,…,T-1; q=-1,…,Q; $\forall$ w

*Probabilities for binomial distributions*

For the binomial distributions in the previous formulas we need a discharge probability per day and per hour. The discharge probability per day, $p_n^{w,q}$, can be calculated from the length of stay distribution, $P^{w,q}(n)$, in the following way.

$$p_n^{w,q} = \frac{P^{w,q}(n)}{\sum_{k=n}^{L^{w,q}} P^{w,q}(k)}$$ for n=0,…,Q-q; q=-1,…,Q; $\forall$ w

We assume that the discharges are distributed over the day according to a constant pattern, $percd_t^w$. In the model of Smeenk (2011) this division of the discharges over the day depends on the treatment type and the day. However, we assume, without loss of generality, that the discharge pattern does not depend on these factors, but that it might differ per ward. The discharge probability per hour, $p_{n,t}^{w,q}$, is the probability that a patient is discharged during a certain hour divided by the probability that the patient was not discharged until now.

$$p_{n,t}^{w,q} = \frac{percd_t^w P^{w,q}(n)}{P^{w,q}(n)\sum_{k=t}^{T-1} percd_t^w + \sum_{k=n+1}^{L^{w,q}} P^{w,q}(k)}$$ for n=0,...,Q-q; t=0,...,T-1; q=-1,...,Q; $\forall$ w

Because we know the treatment types of the scheduled patients we can say more about the length of stay distribution, $\mathrm{P}^{w,q}(n)$, than in the model of Smeenk (2011). We assume that the distribution for the length of stay, $O^j(x)$, depends on the treatment type, j, and that the number of patients of a certain treatment type in a group, $u^{w,q,j}$, is known.

$$\mathrm{P}^{w,q}(n) = \frac{\sum_{j=0}^{J^w} u^{w,q,j} O^j(n)}{\sum_{j=0}^{J^w} u^{w,q,j}}$$ for n=0,...,Q-q; q=0,...,Q; $\forall$ w

For the patients already present in the hospital this distribution also depends on the number of days a patient is already in the hospital, v. $u_v^{w,-1,j}$ is the number of patients of type j already v days present at ward w.

$$\mathrm{P}^{w,-1}(n) = \frac{\sum_{j=0}^{J^w} \sum_{v=1}^{L^{w,-1}} u_v^{w,-1,j} O^j(n+v)}{\sum_{j=0}^{J^w} \sum_{v=1}^{L^{w,-1}} u_v^{w,-1,j}}$$ for n=0,...,Q; $\forall$ w

<u>Calculations for groups of non-scheduled clinical patients</u>
We assume the number of non-scheduled patients depends on the weekday and not on the specific day. Therefore we rewrite the distributions to distributions per weekday and for n days after being admitted, $g_{n,t}^{w,r}(x)$.

$$\overline{g}_{m,t}^{w,q}(x) = \begin{cases} 1 & m < q, x = 0 \\ 0 & m < q, x > 0 \\ g_{m-q,t}^{w,r}(x) & m \geq q, with\ \ r\ as\ \ weekday\ \ of\ \ day\ \ m \end{cases}$$

for m=0,...,Q; t=0,...,T-1; q=0,...,Q; $\forall$ w

*1. Distribution for the day of admission*

On the day of admission we calculate the number of patients using a Poisson distribution. At the beginning of the day no patients arrived yet (step 1.1). During the rest of the day (step 1.2) the probability of x patients is the probability that y patients arrived during the previous timeslot times the probability that x-y patients were present at the beginning of that timeslot.

$$g_{0,t}^{w,r}(x)=\begin{cases} 0 & t=0 \\ \sum_{y=0}^{x}\frac{\left(E[nsa_r^w]*perca_{t-1}^w\right)^y e^{-(E[nsa_r^w]*perca_{t-1}^w)}}{y!}g_{0,t-1}^{w,r}(x-y) & t=1,\ldots,T-1 \end{cases}$$

for t=0,…,T-1; r=1,…,R; $\forall$ w

*2. Distribution for the other days*

On the days after admission we again first calculate the distribution at the beginning of the day, $g_n^{w,r}$, (step 2.1) and then the distributions for the rest of the day, $g_{n,t}^{w,r}$ (step 2.2). Both are based on a binomial distribution, with discharge probabilities $o_n^w$ and $o_{n,t}^w$.

$$g_n^{w,r}(x)=\begin{cases} \frac{\left(E[nsa_r^w]\right)^x e^{-E[nsa_r^w]}}{x!} & n=1 \\ \sum_{k=x}^{\infty}\binom{k}{x}(o_{n-1}^w)^{k-x}(1-o_{n-1}^w)^x g_{n-1}^{w,r}(k) & n=2,\ldots,Q \end{cases}$$ for n=1,…,Q; r=1,…,R; $\forall$ w

$$g_{n,t}^{w,r}(x)=\begin{cases} g_n^{w,r}(x) & t=0 \\ \sum_{k=x}^{\infty}\binom{k}{x}(o_{n,t-1}^w)^{k-x}(1-o_{n,t-1}^w)^x g_{n,t-1}^{w,r}(k) & t=1,\ldots,T-1 \end{cases}$$

for n=1,…,Q; t=0,…,T-1; r=1,…,R; $\forall$ w

*Probabilities for binomial distributions*

For the non-scheduled patients we do not have any information about treatment types, so the discharge probabilities are just based on one distribution for the length of stay, $O^{w,ns}(n)$. The discharge probabilities are calculated in the same way as for the scheduled patients.

$$o_n^w=\frac{O^{w,ns}(n)}{\sum_{k=n}^{L^{w,ns}}O^{w,ns}(k)}$$ for n=0,…,Q; $\forall$ w

$$o_{n,t}^w=\frac{percd_t O^{w,ns}(n)}{O^{w,ns}(n)\sum_{k=t}^{T-1}percd_t+\sum_{k=n+1}^{L^{w,ns}}O^{w,ns}(k)}$$ for n=0,…,Q; t=0,…,T-1; $\forall$ w

<u>Calculations for groups of scheduled day care patients</u>

Just as for the scheduled clinical patients we first rewrite the distribution for the different admission hours, $\bar{h}'^{w,o}_{m,t}(x)$, for the ease of the calculations. It now becomes a distribution for n hours after being admitted, $h'^{w,o}_{m,n}(x)$.

$$\bar{h}'^{w,o}_{m,t}(x) = \begin{cases} 1 & t < o, x = 0 \\ 0 & t < o, x > 0 \\ h'^{w,o}_{m,t-o}(x) & t \geq o \end{cases}$$ for m=1,…,Q; t=0,…,T-1; o=0,…,T-1; ∀ w

For the hour of admission (step 1) the number of patients is known with certainty and for the other hours (step 2) we use a binomial distribution.

$$h'^{w,o}_{m,n}(x) = \begin{cases} 1 & n = 0, x = sa^{w}_{m,t} \\ 0 & n = 0, x \neq sa^{w}_{m,t} \\ \sum_{k=x}^{sa^{w}_{m,t}} \binom{k}{x} (p'^{w,o}_{m,n-1})^{k-x} (1 - p'^{w,o}_{m,n-1})^{x} h'^{w,o}_{m,n-1}(k) & n = 1,\ldots,T-1-o \end{cases}$$

for m=1,…,Q; n=0,…,T-1-o; o=0,…,T-1; ∀ w

*Probabilities for binomial distribution*

The discharge probability per hour, $p'^{w,o}_{m,n}$, is the probability that a patient is discharged during a certain hour divided by the probability that the patient was not discharged until now.

$$p'^{w,o}_{m,n} = \frac{P'^{w,o}_{m}(n)}{\sum_{k=n}^{L^{w,o}_{m}} P'^{w,o}_{m}(k)}$$ for m=1,…,Q; n=1,…,T-1-o; o=0,…,T-1; ∀ w

Just like for the scheduled clinical patients we know the treatment types of the patients. Therefore we use the length of stay distribution per treatment type, $O'^{j}(n)$, and the number of patients of that type, $u'^{w,o,j}_{m}$, to calculate the length of stay distribution per group of patients, $P'^{w,o}_{m}(n)$.

$$\mathrm{P}'^{w,o}_{m}(n) = \frac{\sum_{j=0}^{J^{w}} u'^{w,o,j}_{m} O'^{j}(n)}{\sum_{j=0}^{J^{w}} u'^{w,o,j}_{m}}$$ for m=1,…,Q; n=1,…,T-1-o; o=0,…,T-1; ∀ w

<u>Calculations for groups of non-scheduled day care patients</u>

Here again we need to rewrite the distribution for the different admission hours, $\bar{g}'^{w,o}_{m,t}(x)$, into a distribution for weekdays and for n hours after being admitted, $g'^{w,o}_{r,n}(x)$.

$$\bar{g}'^{w,o}_{m,t} = \begin{cases} 1 & t < o, x = 0 \\ 0 & t < o, x > 0 \\ g'^{w,o}_{r,t-o} & t \geq 0 \end{cases}$$ for m=1,…,Q; t=0,…,T-1; o=0,…,T-1; ∀ w

During the hour of admission (step 1) we calculate the distribution using a Poisson process. For the rest of the hours (step 2) we use a binomial distribution.

$$g'^{w,o}_{r,n}(x)=\begin{cases}\dfrac{\left(E[nsa^{w}_{r}]*perca^{w}_{o}\right)^{x}e^{-E[nsa^{w}_{r}]*perca^{w}_{o}}}{x!} & n=0\\ \sum_{k=x}^{\infty}\binom{k}{x}(o'^{w}_{r,n-1})^{k-x}(1-o'^{w}_{r,n-1})^{x}g^{w,o}_{r,n-1}(k) & n=1,...,T-1-o\end{cases}$$

for r=1,…,R; n=0,…,T-1-o; o=0,…,T-1; $\forall$ w

*Probabilities for binomial distribution*

The probability that a patient is discharged during a certain time slot, $o'^{w,o}_{r,n}$, is based on a length of stay distribution for all non-scheduled day care patients, $O'^{w,ns}(n)$.

$$o'^{w,o}_{r,n}=\frac{O'^{w,ns}(n)}{\sum_{k=n}^{L^{w,ns}}O'^{w,ns}(k)}$$

for r=1,…,R; n=0,…,T-1-o; o=0,…,T-1; $\forall$ w

## Appendix J – Explanation expected number of discharges

Discharges of clinical patients per day

We divide the number of discharges into scheduled, $E[sd_m^w]$, and non-scheduled, $E[nsd_m^w]$.

$E[d_m^w] = E[sd_m^w] + E[nsd_m^w]$ for m=0,…,Q; $\forall$ w

We divide this into discharges from patients admitted at different days, $E[sd_m^{w,q}]$ and $E[nsd_m^{w,q}]$.

$E[sd_m^w] = E[sd_m^{w,-1}] + E[sd_m^{w,0}] + ... + E[sd_m^{w,Q}]$ for m=0,…,Q; $\forall$ w

$E[nsd_m^w] = E[nsd_m^{w,0}] + E[nsd_m^{w,1}] + ... + E[nsd_m^{w,Q}]$ for m=0,…,Q $\forall$ w

The expected number of discharges for a certain group of patients at that hour is then the probability of a certain length of stay, $\mathrm{P}^{\mathrm{w,q}}(m-q)$ and $\mathrm{O}^{\mathrm{w,ns}}(m-q)$, multiplied by the expected number of admissions for that group, $\sum_{t=0}^{T-1} E[sa_{q,t}^w]$ and $E[nsa_r^w]$.

$E[sd_m^{w,q}] = \mathrm{P}^{\mathrm{w,q}}(m-q) * \sum_{t=0}^{T-1} E[sa_{q,t}^w]$ for m=0,…,Q-q; $\forall$ w; q=0,…,Q

$E[nsd_m^{w,q}] = \mathrm{O}^{\mathrm{w,ns}}(m-q) * E[nsa_r^w]$ for m=0,…,Q-1; $\forall$ w; q=0,…,Q

Discharges of clinical patients per hour

For the calculation for the number of discharges per hour, $E[d_{m,t}^w]$, we assume that the discharges are distributed over the day according to a constant pattern, $percd_t^w$.

$E[d_{m,t}^w] = E[d_m^w] * percd_t^w$ for m=0,…,Q; t=0,…,T-1; $\forall$ w

Discharges of day care patients per hour

The structure of the calculations is the same as for the number of clinical discharges per day. Therefore we do not discuss the formulas in detail.

$E[d'^w_{m,t}] = E[sd'^w_{m,t}] + E[nsd'^w_{m,t}]$ for m=0,…,Q; t=0,…,T-1; $\forall$ w

$E[sd'^w_{m,t}] = E[sd'^{w,0}_{m,t}] + E[sd'^{w,1}_{m,t}] + ... + E[sd'^{w,T-1}_{m,t}]$ for m=0,…,Q; t=0,…,T-1; $\forall$ w

$E[sd'^{w,o}_{m,t}] = \mathrm{P'}^{\mathrm{w,o}}_{\mathrm{m}}(t-o) * E[sa_{m,o}^w]$ for m=0,…,Q; t=0,…,T-1-o; $\forall$ w, o=0,…,T-1

$E[nsd'^w_{m,t}] = E[nsd'^{w,0}_{m,t}] + E[nsd'^{w,1}_{m,t}] + ... + E[nsd'^{w,T-1}_{m,t}]$ for m=0,…,Q; t=0,…,T-1; $\forall$ w

$E[nsd'^{w,o}_{m,t}] = \mathrm{O'}^{\mathrm{w,ns}}(t-o) * E[nsa_r^w] * perca_t^w$ for m=0,…,Q; t=0,…,T-1-o; $\forall$ w, o=0,…,T-1

Discharges of day care patients per day

We calculate the number of discharges per day, $E[d'^w_m]$, by adding the expected numbers per hour.

$E[d'^w_m] = \sum_{t=0}^{T-1} E[d'^w_{m,t}]$ for m=0,…,Q; $\forall$ w