MASTER

# Admission planning related to bed capacity constraints

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# Admission planning related to bed capacity constraints

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## Abstract

In this research a mathematical model is developed for the creation of tactical plans based on the relation between the admission planning and the bed capacity. The mathematical model (MILP) minimizes the bed deficit, the bed surplus and the number of wrong hospitalizations. The admission planning focuses on patients with and without receiving a surgical operation during their length of stay in the hospital. The analysis of the clinical pathways of the specialism surgery at both locations of the Zuyderland Medical Center showed that the planning of the operating rooms was not related to the bed capacity. So in this case a unit logistics point of view is used, because the operating rooms are optimally planned without concerning the consequences for the available bed capacity. It is therefore possible that patients are cancelled or hospitalized at another nursing unit than the surgery nursing unit (wrong hospitalization). This is the reason why a mathematical model is created which shows that the operating room unit and the intensive care unit, nursing unit and daycare unit are in fact related to each other and cannot be seen as separate units. In this way a unit logistics point of view is transformed to a chain logistics point of view.

## Preface

This report is the graduation thesis in completion of the master program Operations Management and Logistics (for Healthcare) at the Eindhoven University of Technology. This project closes a period of five interesting and fun years at the university. The graduation period was not always easy, especially the first months were very frustrating. However, I'm glad that I find the courage to continue and that I was able to finish my graduation period with a master thesis which became very interesting in the end.

First of all, I want to thank my mentor H.P.G. van Ooijen for giving me the opportunity to execute my master thesis project in the healthcare environment which is not his main field of research. I really appreciate his support during my graduation period also during the period in which I was not very motivated to continue. It was always easy to make appointments and during those appointments there was always enough time to discuss all the things I wanted to discuss. During our discussions I never got direct answers to my questions or a direction to follow. By this way of working, I have learned; to trust on my own opinion, to be less uncertain about my own capabilities and to be less uncertain about making a wrong decision. I'm really thankful for this.

Second, I want to thank my second supervisor N.P. Dellaert for providing some extra insights in the healthcare environment. During one of our first meetings, he was not very enthusiastic about my conceptual mathematical model; however, during our last meeting he said that the final mathematical model has become interesting. This provided me with some extra self- confidence about my master thesis.

Then, I would like to thank my hospital supervisors, Paul Kuipers (Heerlen) and Nol Visschers (Sittard) for giving me the opportunity to graduate in an environment of my first choice. They facilitated a nice place to work on my master thesis and always tried to schedule meetings at short notice. I also want to thank the other employees at the business control unit in Sittard for being helpful when this was needed and for asking me to join their "team" lunches. Also Karin Schurmann (Sittard) and Twan Regli (Heerlen) deserve some attention, because both were always supportive and they were always willing to make time for me.

Next, I would like to thank my parents for supporting my choices during my entire study and for giving me the opportunity to study.  I want to thank my friends for providing some nice distraction during my graduation period. I specially would like to thank Marlijn Scheepens for her critical way of judging my mathematical model. The last person I want to thank is my boyfriend, Jarno for being patient with me and for believing in me. He really helped to place some events in perspective which softened my frustrations about some situations.

# Executive summary

This report is the graduation thesis in completion of the master program Operations Management and Logistics (for Healthcare) at the Eindhoven University of Technology.

**Introduction**

This report is based on a case study at the Zuyderland Medical Center in Sittard and Heerlen. The Zuyderland Medical Center has its origins in Orbis Medical Concern in Sittard and Atrium Medical Center in Heerlen. The financial pressures, the enhancement of their bargaining position and the urge to streamline and improve the delivery of healthcare have led to the merger of both hospitals.

For this reason a merged capacity management model which is equal for both locations should be developed. This model should provide the Zuyderland Medical Center with information about capacity management principles at a tactical level. The intended capacity management model has to be based on network logistic principles, which means that all departments and resources within a hospital need to be investigated. This was not possible during the time horizon of this thesis, therefore is chosen to focus on the development of a capacity management model which is tested for the specialism surgery. After some research was done, the scope was further defined to a focus on the units; operating rooms, intensive care, nursing unit and daycare unit.

Articles found in literature mainly focus on the relation between the operating room planning and some bed capacity constraints. However, in this thesis not only the patients who received a surgical operation are taken into account, also the patients who did not receive a surgical operation. The choice was therefore made to develop a tactical plan which relates the admission planning to the bed capacity. This tactical plan is based on the development of a mathematical model (MILP) which relates the admission planning to the bed capacity by minimizing the bed deficit, bed surplus and the number of wrong hospitalizations.

**Main findings**

The differences in the clinical pathways for surgery at both locations show that the operating room planning is not related to the bed capacity. It is therefore possible that surgical operations are cancelled or patients are hospitalized at different nursing units than the nursing unit of the operating specialism.

The number of wrong hospitalizations over the year 2014 was equal to two patients per day in Sittard and four patients per day in Heerlen. This means that every day bed deficit was created because otherwise patients should not have been hospitalized at a different nursing unit. It is therefore important to take into account the number of wrong hospitalizations.

The focus should be placed on clinical patients and daycare patients, since many surgical operations are nowadays performed by daycare surgery instead of clinical surgery and because of the fact that both clinical surgeries and daycare surgeries are performed at the same operating rooms. This means that the operating room occupancy is depended on both clinical surgeries and daycare surgeries.

The urgent patient flow is also taken into account, since emergent patients arriving during the day could affect the planned operating room schedule. It is therefore important to reserve some OR capacity per day for the urgent patient flow. In this way, it becomes less common that patients should be cancelled because of an emergent patient.

It is important to take into account patients with and without receiving a surgical operation since both groups are occupying a clinical bed or a daycare bed during their length of stay. When patients hospitalized without receiving a surgical operation are not taken into account, it is not possible to create a realistic representation of reality. When our mathematical model is then used in practice, it might not be possible to draw realistic conclusions and create a tactical plan based on the results of the mathematical model.

Our mathematical model is translated to a MS Excel Solver tool which is tested with the use of historical data of Sittard and Heerlen. The test run did not show an integer solution for both locations, therefore a scenario analysis was executed to show that an integer solution with no bed deficit and not wrong hospitalizations existed for both locations.

The results of the scenario analysis of Sittard showed that the reserved operating room capacity for the urgent patient flow was too large which meant that there was not enough operating room capacity left to treat the elective patient flow. After changing the reserved capacity for the urgent patient flow, an integer solution existed.

The scenario analysis results of Heerlen show that no integer solution existed because the bed occupancy at the nursing unit was higher than 1. After increasing the maximum available bed capacity at the nursing unit, an integer solution appeared. Another remarkable thing discovered during the scenario analysis was that the available operating room hours in 2 weeks contained 100 hours more than needed to treat all elective patients.

The fact that no integer solution existed for both locations in the first place, can be explained by the separate planning of the operating rooms and the bed capacity at the wards. When problems existed in reality, last moment arrangements are used to control the situation. This is the reason why wrong hospitalizations are created. Another reason can be found in the fact that our mathematical model uses a flexible operating room schedule which means that every patient is planned in the operating room schedule at a day which is "optimal" for the operating rooms and for the wards. Both suggestions can be seen as reasons for the fact that our mathematical model shows no bed deficit and no wrong hospitalizations at the nursing unit for Sittard and Heerlen.

It is important for hospitals to understand the principles of chain logistics which are in this case based on the connection between the operating rooms and the wards. Both units are not operating on its own. The creation of a bottleneck at one unit directly implies the creation of a bottleneck at the other unit. So the admission planning should always be related to the bed capacity.

**Recommendations**

Recommendations with regard to the tactical planning are based on the use of our mathematical model for the determination of; the required number of IC, NU and DC beds, the required number of operating room blocks per week, the operating room capacity needed for elective patients per week, the operating room capacity needed for emergent patients per week, the order of the operating room blocks, the expected length of stay per patient category and the allowed number of wrong hospitalizations per day.

Other recommendations are focused on; the creation of one clinical pathway equal for Sittard and Heerlen, the use of a flexible operating room schedule in the future, the use of chain logistics approaches instead of unit logistics approaches, the running of our mathematical model for the whole hospital to create insight in the current situation and the availability and completeness of the data sets provided by the hospital used for financial and logistics purposes.

# List of abbreviations

| | |
|---|---|
| *DC* | Daycare unit |
| *EHD* | Emergent Hospitalization Department |
| *IC* | Intensive Care |
| LOS | Length Of Stay |
| *MC* | Medical Center |
| *MILP* | Mixed Integer Linear Programming |
| *MS* | Microsoft |
| *NU* | Nursing Unit |
| *OR* | Operating Room |
| *OT* | Operation Theatre |
| *POR* | Policlinic Operating Room |
| *POS* | Pre-Operative Screening |
| *SHU* | Sober Hospitalization Unit |

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# 1. Research introduction

This chapter forms the introduction to the research done in this thesis. Section 1.1 provides information about the healthcare environment since this can be seen as the field of research. In section 1.2 the differences between healthcare and other industries are displayed. Section 1.3 is concerned with the company description and a description of the subject of this thesis.

## 1.1 The healthcare environment

A hospital can be described as a wide range of services and functional units which provide care to relieve patient suffering (Kumar, 2011). Recently, financial pressures force hospitals to serve more patients with the same amount of available resources (Litvak & Bisognano, 2011). Standardization of processes within hospitals is difficult since this requires physicians to adapt to processes. The standardization of processes could lead to improved efficiency and obtained economies of scale (Thompson, et al., 2013).

In order to deal with the financial pressures, healthcare organizations are becoming larger, because larger organizations have the ability to dedicate resources to initiatives that would not be economically feasible for smaller organizations. Becoming larger (through internal growth initiatives or through mergers and acquisitions) also brings growth in complexity, healthcare organizations are expanded horizontally and vertically[1] across the healthcare chain (Jack & Powers, 2009) (Thompson, et al., 2013).

Merger activity results in networks of hospitals, which are formed to enhance the hospitals' bargaining position with payers and suppliers. An important goal is often to streamline and improve the delivery of health care. In those situations it could be advantageous to offer a particular clinical service[2] at one single location (Green, 2004) (Jack & Powers, 2009). In this way, the merger gives the opportunity to combine resources and to specialize in particular clinical services since some particular clinical services will only be provided at a single location of the merged organization.

Those large and complex healthcare organizations need to be managed and organized well in order to increase efficiency and patient satisfaction. Healthcare operations management can be used in this situation and is defined as; the quantitative management of the supporting business systems and processes that transform resources (or inputs) into healthcare services (outputs)[3]. The goals of operations management are to reduce costs, reduce variability, improve productivity, improve quality of customer service and continuously improve business processes (Kumar, 2011). Models created with the use of operations management should enable the operations managers to better understand problematic situations, to generate potential improvements and to evaluate those potential improvements (Worthington, 2007).

## 1.2 Differences between healthcare and other industries

The challenge of every industry is to match highly fluctuating demand with current and available capacity. This challenge requires effective demand management and capacity management strategies (Jack & Powers, 2009). A fundamental distinction between healthcare and other service industries is that healthcare is not a service which is daily demanded by people. This does not mean that healthcare

[1] Horizontal integration focuses on operating two or more organizations that perform the same function within the healthcare value chain. Vertical integration focuses on operating organizations that perform different functions within the healthcare value chain.

[2] A clinical service can be seen as a treatment/service provided by a specific specialty. The characteristics of clinical services are small patient demands or services which involve unique technologies and skills.

[3] Inputs can be seen as resources and assets such as labor and capital, including cash, technology, personnel, space, equipment, and information. Outputs are defined as the actual production and delivery of health care services.

is not highly valued, people consume healthcare only when it is needed (Thompson, et al., 2013). This is one of the reasons why the decision making in healthcare does not follow logical processes as used in other industries. In not healthcare related industries decisions are often driven by goal alignment for both managers and owners. Decision making tends to follow cost benefit models and focuses on risk minimization, cash flows and return on investment. In the healthcare sector there is incomplete alignment of goals between different agents or managers, because of unclear goals, complex organizations and ambiguous relationships (independency between departments) (Langabeer II, 2008).

## 1.3 Company description

This report is based on a case study at the Zuyderland Medical Center (MC) in Sittard and Heerlen. The Zuyderland MC has its origins in Orbis Medical Concern in Sittard and Atrium Medical Center in Heerlen. The financial pressures, the enhancement of their bargaining position and the urge to streamline and improve the delivery of healthcare have led to the merger of both hospitals.

Based on the annual reports of 2014 a comparison in key numbers between the location Sittard and the location Heerlen can be made. Table 1 shows the key numbers based on the number of beds, the number of daycare hospitalizations, the number of clinical hospitalizations, the number of policlinic visits and the average length of stay.

| **Sittard** | | **Heerlen** | |
|---|---|---|---|
| # Clinical beds | 425 | # Clinical beds | 468 |
| # Daycare beds | 50 | # Daycare beds | 70 |
| # Daycare hospitalizations | 21.106 | # Daycare hospitalizations | 38.272 |
| # Clinical hospitalizations | 17.855 | # Clinical hospitalizations | 26.745 |
| # Policlinic visits | 363.284 | # Policlinic visits | 479.871 |
| Average length of stay (days) | 4,3 | Average length of stay (days) | 5,4 |

*Table 1: Key numbers Sittard and Heerlen*

The Zuyderland MC wants to provide high quality care in a safe environment. The allocation of the resources is targeted to quality, safety, innovation and education in a financial healthy environment. The mission and statement of Zuyderland MC are based on providing cure and care. Cure in a sense that the hospital wants to deliver excellent, innovative patient care in a welcoming environment with regard to the improvement of life quality in collaboration with their partners. The care part of the mission and statement wants to create the possibility for patients to live as long as possible at home with excellent, regional care (Atrium-Orbis., 2014).

The mission and statement can only be accomplished when changes in the way healthcare is provided are continued. Many surgical operations are now performed by daycare, so the patient is not hospitalized after the surgical operation. In the future, some treatments which are now executed by daycare, will become part of the job of the general practitioner. This means that hospitals can decrease the number of clinical beds and in the future also the number of daycare beds.

Some physicians have to perform a specific number of surgical operations a year, this is not possible anymore when physicians are only able to operate at one hospital. The rule implies that the physician can only perform very specific and complex surgical operations when the minimum target is reached.

If this is not possible the physician is not allowed to perform any of those specific and complex surgical operations in the future. These rules are set by insurance companies and the IGZ (Inspectie voor de Gezondheidszorg) to be sure about the abilities and capacities of the physicians who are performing those complex surgical operations. The determination of those rules together with the decrease in clinical beds and daycare beds, provides an opportunity for hospitals to collaborate more intense or to merge. The subject of this thesis and the related problems to the subject are described beneath and are also related to the earlier described problems in the healthcare environment section.

### *1.3.1 Company problem description*

At the moment, both locations (Sittard and Heerlen) of the Zuyderland MC use different models with regard to capacity management. Towards the end of the merger, a merged capacity management model should exist which is equal for both locations. This model should provide the Zuyderland MC with information about capacity management principles at a tactical level.

When the merger progresses, the Zuyderland MC will have policlinic departments at both locations; however, the surgical operations of specific specialism will only be performed at one location. It is therefore possible that the policlinic pathway of a patient starts at a different location than the location where the clinical pathway ends. When surgical operations are allocated to a specific location, a capacity management model should provide insight in the consequences related to; for example, the operating room capacity and the bed capacity at the nursing units. The number of patients treated at both locations should stay more or less the same. It is not possible to facilitate much more capacity at one of the locations. So this makes it important to create an integrated capacity management model which is used for both locations.

# 2. Research description

This chapter displays in section 2.1 a detailed literature review based on the subject of this thesis. In section 2.2 the analytical approaches found in literature related to the subject of the thesis are described. The last section of this chapter is concerned with the description of the research assignment.

## 2.1 Literature review

Many articles about healthcare operations management describe ways to improve capacity/demand management, to improve the patient flow and to improve the use of resources. An organization is structured around operations, those operations involve activities to create value. Operations can be seen as activities that transform inputs into outputs and thereby adding value. The characteristics of operations determine the way operations (and processes) can be planned and controlled. When a process or chain uses many shared resources including a bottleneck resource, the process is much more difficult to organize than a process with no shared resources. A reason for this is that in a process with shared resources, processes have to compete for resources (Vissers & Beech, 2005).

### *2.1.1 Demand/ capacity management*

Capacity management deals with ensuring that the organization has the capability to respond to the level of demand experienced. The use of good demand and capacity management strategies can have significant impact on organizational performance such as, increase the quality of care outcomes, increase efficiency and increase financial performance (Jack & Powers, 2009).

The complexities of hospital capacity planning and management exist because of:

- Interdependencies of various parts of the hospital
- The need to identify bottlenecks which may change accordingly
- The variety of both fixed capacity (inpatient beds, ED beds, diagnostic equipment) and variable capacity (nurses, physicians, technicians) that must be managed.
- Shared resources, which requires policies and procedures to allocate resources among different patient groups.
- Time dependency and seasonality (Green, 2004)

Those complexities can increase the possibility of the existence of a mismatch between capacity and demand at a certain point in time. When a mismatch between capacity and demand exists, the organization can choose; to increase the capacity level, to identify the bottlenecks and eliminate them, to reduce demand, or to transfer demand from other areas (Langabeer II, 2008).

A bottleneck can be seen as a point in the process where the demand exceeds the available capacity. A person, a role or any other barrier or obstacle to cooperation and work performance among departments can be characterized as a bottleneck (Langabeer II, 2008). When there is no balance in the allocated capacities to specialties, one capacity may always be overloaded and thus becoming the bottleneck of the process. The consequence for the other resources is to be under used (Vissers, 1994). A bottleneck at the end of the process results in waiting times and inefficiency that can eventually affect the entire system. Only eliminating the bottleneck at the beginning of the process, will not increase the throughput. This means that all processes should be studied systematically and identification of those obstacles that really limit capacity is important for the overall performance of the process (Langabeer II, 2008).

### *2.1.2 Resource allocation*

In order to provide hospital services, a number of specialized resources is needed including; human resources (physicians and nurses), technological resources (CT scanners and lab specimen processing equipment) and physical resources (beds and rooms). When one of those resources is not available, the delivery process stops and the patient has to wait (Thompson, et al., 2013). Those specialized resources can be seen either as leading resources (trigger the production of following resources) or following resources. The utilization rate of a resource is defined as the ratio between its utilized capacity and its available capacity. In order to improve hospital resource allocation, it is important to include specialist- time as a resource (leading) in the allocation procedure (Vissers, 2005).

The allocation of resources is dependent on different important factors:

- The urgency level of operations which affects prioritization decisions
- The length of the process, in terms of the number of operations that constitute the chain.
- The complexity of the process
- The predictability of the process
- The volume of the patient flow
- The use of shared resources or a bottleneck resource

All those factors are related to each other, since higher patient volumes means that potentially more data is available to investigate the characteristics of the processes in terms of complexity and predictability. The complexity of the process influences the way the process can be designed and planned. Designing and planning of a process is influenced by its predictability, which gives proof for the relationship between complexity and predictability of a process (Vissers, 2005) (Vissers & Beech, 2005).

### *2.1.3 Patient flow*

Hospitals are originally organized around specialties and departments instead of being organized around patients' needs. A large part of the time patients spend in hospitals include waiting time, which increases by inefficient management of admission and discharge (Rechel, et al., 2010). Maintaining efficiency in operations, means that organizations need to optimize patient and other process flows. This means that the organization has to understand the patient demand by aligning capacity and resources with demand, by using de- bottleneck approaches to improve throughput and by managing patient and asset flows (Langabeer II, 2008). It is very important that each patient travels along the shortest path possible within the network, encountering as few delays at bottlenecks as possible (Rechel, et al., 2010).

A clinical pathway can be seen as the path the patient follows through the healthcare system. Those different clinical pathways can be compared into one patient flow; for example, the elective patient flow and the urgent patient flow (Tànfani & Testi, 2012).

The development of patient groups is based on routine versus non routine processes. For routine processes it is possible to define a treatment path (clinical pathway); however, for non- routine processes it is not possible to define a predetermined treatment path. The reason for this is that the predictability of resource use in non- routine processes is much lower than the predictability of resource use in routine processes (Vissers & Beech, 2005).

The flow of patients should consist of a homogenous group of patients in which the pathway is characterized not only by clinical characteristics specified per specialty but also by a set of attributes that describe the resource requirements (Tànfani & Testi, 2012). This means that homogeneity concerns both the market performance (similar criteria for urgency and acceptable waiting times) and the production process (products within patient groups use the same constellation of resources) (Merode, et al., 2004).

Some variation can be found in the healthcare delivery system. The variation caused by the randomness of the disease is called natural variation, and can be accommodated by managing demand based on historical data and queuing methods. Natural variation can also be caused by different levels of staff competency and clinical abilities which should be managed. The other form of variation is artificial variation which can be seen as personal preferences and beliefs of individual physicians. The effect of artificial variation on the flow far exceeds the natural variation, which is the reason why emphasis needs to be placed on change concepts related to the reduction of the artificial variation in healthcare delivery. The patient flow is dependent on the variation found in different healthcare processes. So the key concept of improving the patient flow can be found in reducing variation in processes related to the patient flow (Hulshof, 2013).

#### *2.1.4 Production control/ planning framework*

A framework for a hospital does not describe an optimal way of working or controlling activities, it describes a logical way of coordinating hospital activities within the perspective of the current hospital organization. A framework serves as a reference background to show the weak points in the process and should not be implemented (Vissers, et al., 2005).

Production control in health care is defined as follows: " the design, planning, implementation and control of coordination mechanisms between patient flows and diagnostic & therapeutic activities in health service organizations to maximize output/ throughput with available resources, taking into account different requirements for delivery flexibility (elective/ appointment, semi-urgent, urgent) and acceptable standards for delivery reliability (waiting list, waiting times) and acceptable medical outcomes" (Bertrand & Vries, 2005).

The development of a production and control framework in healthcare should be bottom-up, from the operational level to the tactical level (allocation of resources) and to the strategic level (objectives and targets). The strategic and tactical level can be seen as macro level modeling and the operational level can be seen as micro level modeling (Rohleder, et al., 2013). The requirements for the patient flow and the resources need to be established and coordinated at each level of planning (Vissers, et al., 2005). The strategic level can be seen as the determination level of objectives and the use of resources to achieve those objectives. The tactical level uses resources to accomplish the objectives stated at the strategic level. At the operational level, tactical decisions to achieve the strategic objectives in the current daily activity are linked (Tànfani & Testi, 2012). Every level in the framework needs horizontal control to match patient flows with resources and vertical control to check whether activities are developed within the boundaries set by higher levels. Operational control is the process of assuring that specific tasks are performed effectively and efficiently (Vissers, 1994).

At the operational level the principle of a job shop used in the industry can be applied to the healthcare environment. A job shop can be seen as a network of workstations capable of producing a wide variety of jobs. A workstation is used as a basic unit for allocating resources. This workstation can be seen as a processing point in the production chain, which needs a mix of resources to contribute to production. One of the resources is used as a basis for allocation, the amount of other resources needed is defined by a fixed relationship between capacities in the workstation. A workstation in a hospital consists most of times of a combination of personnel, accommodation, equipment and specialist time. The specialist decides where to allocate the available time to, which makes it hard to control this capacity within the workstation. However, the specialist time is essential to produce, which makes the specialist capacity a critical resource for the workstation. Specialist time is divided over different workstations in the hospital and can thus be seen as a shared resource (Vissers, 1994). For this reason production control in healthcare organizations differs from production control structure for manufacturing organizations, since the allocation of specialist- time as a resource should be shared between patient groups (Vissers, et al., 2005).

From an operations research perspective, coordination is about having the right quantities of healthcare resources and about managing those resources together. Coordination is important during capacity planning, since hospitals want to avoid duplication of services and a lack of coordination can lead to delays in patient treatment. Shortages of key resources at the long run may lead to bottlenecks and long waiting times. As a result, poor coordination of healthcare resources may lead to poor quality and higher costs (Rohleder, et al., 2013).

### *2.1.5 Network logistics*

It is important to understand that a framework based on operations management principles on its own is not enough to:

- Increase efficiency
- Reduce costs
- Reduce variability
- Improve productivity
- Improve quality of customer service
- Improve business processes (Langabeer II, 2008)

Hospitals organize their available beds into nursing units (NU) that are used by one or more clinical disciplines. Classifications such as length of stay, level of care or urgency are becoming more important next to clinical service. The decisions about the number of beds in a hospital are often not based on a quantitative approach. The hospital registration is based on some production parameters, such as number of admissions, daycare treatments, nursing days and number of outpatient visits (de Bruin, et al., 2010). The variability in admissions and lengths of stay inherently leads to variability in bed occupancy (Bekker & Koeleman, 2011). It is therefore important to face a trade-off between the high complexity of a holistic view and the danger of suboptimal solutions resulting from a focus on the isolated units, when planning the Operation Theatre (OT) and the downstream units (Fügener, et al., 2014).

Fügener, et al., 2014 shows that the importance of understanding the fact that a unit logistics approach[4] and even a chain logistics approach[5] is not enough anymore. The focus should be on a network logistics approach which shows that the optimization of a service in the chains should be balanced with the efficiency in the use of resources in the units. This approach combines the advantages of both the unit logistics approach and the chain logistics approach. For this reason, the network logistics approach makes it possible to avoid a situation in which an improvement in one process will stay unnoticed at the expense of a drawback for other processes (Vissers & Beech, 2005). So in order to understand the patient flow and be able to use resources effectively/ efficiently, an integrated approach is needed which does not only focus on the isolated units but considers the whole system of care (Haraden & Resar, 2004).

The fragmented nature of the healthcare planning and control is the main reason why healthcare is lagging behind manufacturing industries. An integrated approach to healthcare planning and control

[4] Focusing on the total flow of patients using the unit and focusing on the effect of the patient flow on the use of resources and the workload of employees.
[5] Focusing on the entire journey of the patient through the hospital.

can provide improvements, since the planning and control in one department is dependent on the decision making in other departments in the patient's care chain. It seems really important to build an integrated decision framework that is able to cope with multiple resources, multiple time periods and multiple patient groups with various uncertain treatment paths (Hulshof, 2013).

## 2.2 Analytical approaches

Analytical approaches can be used for dimensioning hospital wards, de Bruin, et al., (2010) provide a comprehensive data analysis of 24 clinical wards in a university medical center. The number of admissions and the length of stay distribution were analyzed because both can be seen as the key characteristics of the in-patient flow. In this way occupancy rates for all wards to indicate the bed utilization could be provided. The in- patient flow can be described by the Erlang loss model, which is a standard queuing model (de Bruin, et al., 2010). This model can be used to determine the number of required operational beds and to illustrate the impact of in- patient flow characteristics on ward sizes. The Erlang loss model can be implemented as a decision support system, which provides management information for the evaluation of the current size of nursing units and for the quantification of the impact of bed reallocations and merging wards (de Bruin, et al., 2010). The Erlang loss model is also used by Bekker & Koeleman, (2011) to determine the optimal number of elective admissions per day, such that an average desired daily occupancy is achieved. The disadvantage of a model such as the Erlang loss model, is the fact that this model is based on assumptions regarding the structural characteristics of patient flows and admissions. For this reason not all decisions made at a hospital are captured.

The article by Ma & Demeulemeester, 2013 consists of three stages; the case mix planning phase, the master surgery scheduling phase and the operational performance evaluation. The objective of this article is to improve the patient service level and to minimize the total expected bed shortage by reallocating the bed capacity and by building balanced master surgery schedules. An optimization approach to determine a tactical plan with reserved capacity for emergency patients is designed by Adan, et al., 2011. This model was then used to develop operational strategies to deal with the actual flow of elective and emergency patients on a weekly and daily basis.

## 2.3 Assignment

Hospitals are often organized around the principles of unit logistics, which means that also optimization principles are dedicated to the unit. It should be better to use a chain logistics approach or a network logistics approach. According to the scope, the case study is focused on the specialism surgery. So in this case, the assumptions at the end of the thesis are more dedicated to the use of a chain logistics approach since the focus is on one specialism.

It seems interesting to create clinical pathways which indicate all possible paths the patient can follow through the hospital. As a result of the merger, treated in the case study, patient pathways will be allocated to one specific location. It is therefore possible that the start and end of the patient pathway could be at a different location. Since the performance of the surgical operations and the hospitalizations will be allocated to one location. In this situation two very important units in the hospital should be related to each other, because a bottleneck in one of the units will create a bottleneck in the other unit. Those two units are; the operating room (OR) and the wards. From literature some analytical approaches can be used in relating both units to each other. In order to show the benefits of the use of chain logistics principles, the relationship between the admission planning and the bed capacity should be investigated in more detail. It should be possible to create a tactical plan which is good for the scheduling of the admissions related to the bed capacity. This leads to the following research assignment:

*Develop a tactical plan which relates the admission planning to the bed capacity by minimizing the bed deficit, the bed surplus and the number of wrong hospitalizations.*

The choice is made to use admission planning instead of OR planning since the intended model does not only take into account patients with an OR appointment, it takes also into account patients who do not receive a surgical operation.

Two separate tactical plans are created for both locations of the Zuyderland MC, a combination of both tactical plans should create a reasonable tactical plan for the merged organization Zuyderland MC.

### *2.3.1 Methodology*

In order to be able to answer the research assignment more information about the current way of working at both locations of the Zuyderland MC is needed. First of all, clinical pathways should be created to obtain more insight into the paths a patient can follow through the hospital. The information for creating the clinical pathways is collected by interviewing people in Sittard and Heerlen.

*Sittard*

- Interview with the care planning, in order to collect more information about the current way of planning care and about the current way of planning OR appointments.

- Interview with the central planning, in order to collect more information about the current way of planning hospitalizations and emergent hospitalizations. But also about the current way of providing feedback between the OR planning (care planning) and hospitalization planning (central planning).

- Interview with a policlinic department assistant, in order to gather more information about the current way of working at the policlinic department and about the way patients are referred when an OR appointment is needed.

The information of those three interviews (Appendix E. Interviews) together should be enough to create a clinical pathway with the use of Microsoft (MS) Visio. The clinical pathway created is sent to all interviewed people to receive feedback about misinterpreted concepts.

*Heerlen*

- Interview with the OR planner, in order to collect more information about the current way of planning OR appointments.

- Interview with the hospitalization office, in order to gather more information about the current way of planning care, about the current way of submitting OR requests and informing patients about OR appointments, and about the current way of planning hospitalizations and emergent hospitalizations. This interview should also provide information about the current way of providing feedback between the OR planning (OR planner) and the hospitalization planning (hospitalization office).

- Interview with a policlinic department assistant, in order to collect more information about the referring of patients to other units in het hospital and in particular about the referring of patients for OR appointments.

The information collected in the above described interviews (Appendix E. Interviews) should be enough to create a clinical pathway with the use of MS Visio. The clinical pathway created is sent to all interviewed people to receive feedback about misinterpreted concepts.

The clinical pathways can be used to compare the different paths a patient can follow through the hospital at both locations of the Zuyderland MC. With the use of the interviews and the clinical pathways a comparison between the current way of planning patients for OR and hospitalization should become visible. This comparison can then be used to formulate a mathematical model for developing a tactical plan which relates the admission planning to the bed capacity.

The mathematical model is formulated with the use of literature about the connection between the operation theatre and the wards. In order to create something new or add something to the existing literature, related articles to the subject, such as the articles by Adan, et al., 2011 and Ma & Demeulemeester, 2013, are combined and extended. In order to test the mathematical model, data from both locations of the Zuyderland MC (case study) is used. Form both locations, Sittard and Heerlen, data about the OR planning and the hospitalizations is needed. Historical data from 2014 should be enough to test the visibility of the mathematical model.

The mathematical model is built in the MS Excel solver. When the research problem seems too large for the add -in solver of Excel, an open solver will be used to generate reasonable results.

Two separate tactical plans are created for both locations of the Zuyderland MC. Those tactical plans are compared and combined to draw conclusions about the current situation and about the future situation when patient pathways are crossing locations.

### *2.3.2 Scope*

The case study in this thesis is based on the merger of two hospitals; Orbis medical concern in Sittard and Atrium medical center in Heerlen. In order to create an integrated approach for a hospital, all departments and resources used should be investigated. This was not possible during the time horizon of this thesis. In consultation with the employee business control at the location Sittard and the manager capacity management at the location Heerlen, the choice to focus on the specialism surgery was made. Surgery can be seen as one of the largest specialism with the largest demand for resources in a hospital. When the principles developed in this thesis apply for surgery, they would also apply for less complex specialism.

After the creation of the clinical pathways for both locations of the Zuyderland MC, the largest differences could be found at the way of planning the OR and the hospitalizations. In consultation with the employee business control at the location Sittard and the manager capacity management at the location Heerlen is chosen to focus on the relation between the admission planning and the bed capacity. So the units: Operating rooms, Intensive Care (IC), Nursing unit and Daycare unit (DC) presented in the clinical pathways are considered, the other units presented in the clinical pathways are left out of scope.

# 3. Detailed analysis

This chapter describes a detailed process analysis of the current situation. In section 3.1 the clinical pathways of Sittard and Heerlen are described. A schematic representation of the clinical pathways of Sittard and Heerlen are displayed in Figure 1 and Figure 2. It is important to realize that those clinical pathways are only based on the patient groups within the specialism surgery. Section 3.2 describes the current planning process in Sittard and Heerlen and section 3.3 provides an overview of the planning differences between Sittard and Heerlen based on section 3.2. The largest differences in the planning of patients between both locations can be found in the planning of the OR's and the planning of the bed capacity. Section 3.4 provides therefore more detailed information about the OR planning and bed capacity planning in Sittard and Heerlen. The last section of this chapter gives a zero measurement based on the research assignment.

## 3.1 Clinical pathways

A clinical pathway is the path a patient follows through the healthcare system based on scientific and technical knowledge, and organizational, professional and technological available resources. So the clinical pathway can be seen as an operational tool in the clinical treatment of diseases by using a patient focused point of view (Tànfani & Testi, 2012).

For both locations Sittard and Heerlen, clinical pathways are created to show the differences in the processes between both locations. After the merger is completed, both clinical pathways should become one clinical pathway. It is possible that the clinical pathway of the patient starts in Sittard (policlinic pathway) and ends in Heerlen (clinical pathway) or the other way around.

### *3.1.1 Differences in the clinical pathways*

Figure 1 shows the clinical pathway of Sittard and Figure 2 shows the clinical pathway of Heerlen. Figure 1 and Figure 2 have the same layout. The part above the OR (block 6) is characterized as the policlinic pathway and the part beneath the OR is characterized as the clinical pathway. At both locations, the patient can enter the process via the outpatient department or via the emergency department (block 1; start of the process).

After visiting the outpatient department, the patient can follow different paths:

- To screening and diagnostics, when further investigations are needed to determine the right diagnosis.
- To the Policlinic Operating Room (POR), for minor surgery.
- To the care planning in Sittard and the hospitalization office in Heerlen, when a surgical operation is needed.
- To the Nursing Unit in Sittard and the Emergent Hospitalization Department (EHD) in Heerlen for an urgent hospitalization.
- Discharge, no further treatment is needed.

The screening and diagnostics, the POR, the care planning and the hospitalization office can be seen as the second step in the process the patient follows through the hospital. For this reason a 2 is displayed in the right corner of those blocks in Figure 1 and Figure 2. The blocks; care planning, central planning, hospitalization office and OR planning are colored dark grey, because those entities are more concerned with the planning process (section 2.2 and 2.3) and do not use scarce resources. The care planning in Sittard and the hospitalization office in Heerlen are both part of the clinical pathway since both entities have patient contact, which means that the patient actually visits those entities. The central planning in Sittard and the OR planning in Heerlen do not have patient contact, so both are not seen as directly part of the process. Those entities become important when the planning process and the planning differences are described.

When the patient enters the process via the emergency department in Sittard, the patient can follow the path to the observatorium (block 2), for observation and further investigations. The path directly to the OR (block 6) can be followed, when a surgical operation cannot wait. The patient follows the path to the nursing unit (block 5), in case of an urgent hospitalization or the patient follows the path to the outpatient department (block 1), for a short visit. The last option is discharge right after visiting the emergency department. The only difference with the path followed by the patient in Heerlen is the fact that the patient is always first hospitalized at the EHD (block 2) before other choices are made. It is still possible that the patient is discharged after visiting the emergency department.

When the patient is referred to the care planning in Sittard, the care planning schedules the OR appointment, the Pre- Operative Screening (POS) appointment (block 4) and the appointments for investigations according to protocol together with the patient. The path followed by children is somewhat different, children have to visit the pediatric department and/or the pedagogic department (block 3) before visiting the POS. When the anesthesiologist requests for further investigations or consults, the care planning has to call the patient and schedules the appointments. After this all patient data for the surgical operation is known and the patient can be treated. The care planning also schedules the POR appointment for laser treatments.

After referral for surgical operation in Heerlen, the patient visits the hospitalization office. This department arranges the OR appointment, which means that the patient is placed on a waiting list which is visible for the OR planner. The OR planner schedules the OR appointment for the patient. The hospitalization office informs the patient about the OR appointment and the POS appointment. The appointments for the investigations needed before visiting the POS (block 3) are given to the patient directly at the moment, the patient first visits the hospitalization office.

The central planning in Sittard and the hospitalization office in Heerlen are responsible for the planning of the bed capacity at the different nursing units.

At the day of surgery the patient enters the process via the nursing unit or via the daycare unit in Sittard. The patient enters the process in Heerlen via the Sober Hospitalization Unit (SHU) or via the daycare unit, when the surgical operation is on the same day as the hospitalization of the patient. When the patient is hospitalized one day earlier than surgery takes place, the patient enters the process via the nursing unit. The nursing unit, the daycare unit and the SHU can be seen as the last step in the process before the OR takes place. Since the OR has number 6, the nursing unit, daycare unit and SHU have number 5 in the right corner of their block.

After surgery the patient is hospitalized at the nursing unit, or at the Intensive Care, or at the daycare unit. In Heerlen it is possible to hospitalize the patient after surgery at the EHD, on the condition that the patient has entered the process via the emergency department and that the expected length of stay (LOS) is less than 48 hours. The IC is characterized with a 7 in the right corner of this block. The nursing unit, the daycare department and the EHD could also have number 7 instead of number 5 and 2; however, to be consistent in both figures one way of numbering is chosen to show the differences but also the equalities between both figures.

Figure 1 and Figure 2 show at some places small squares with a number. The squares with the same number correspond to each other. This is done to increase the readability of the figures.

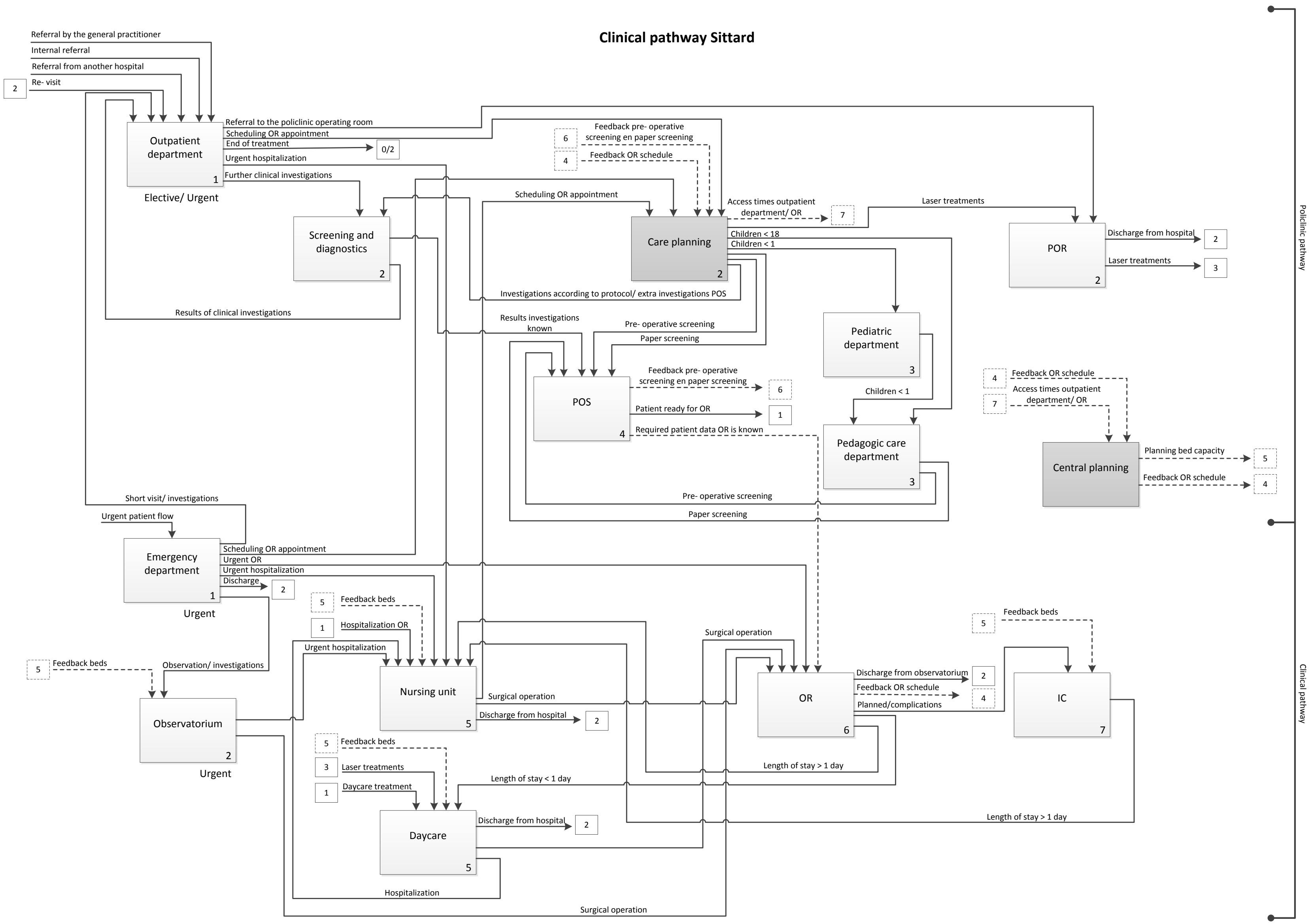


*Figure 1: Clinical pathway Sittard*

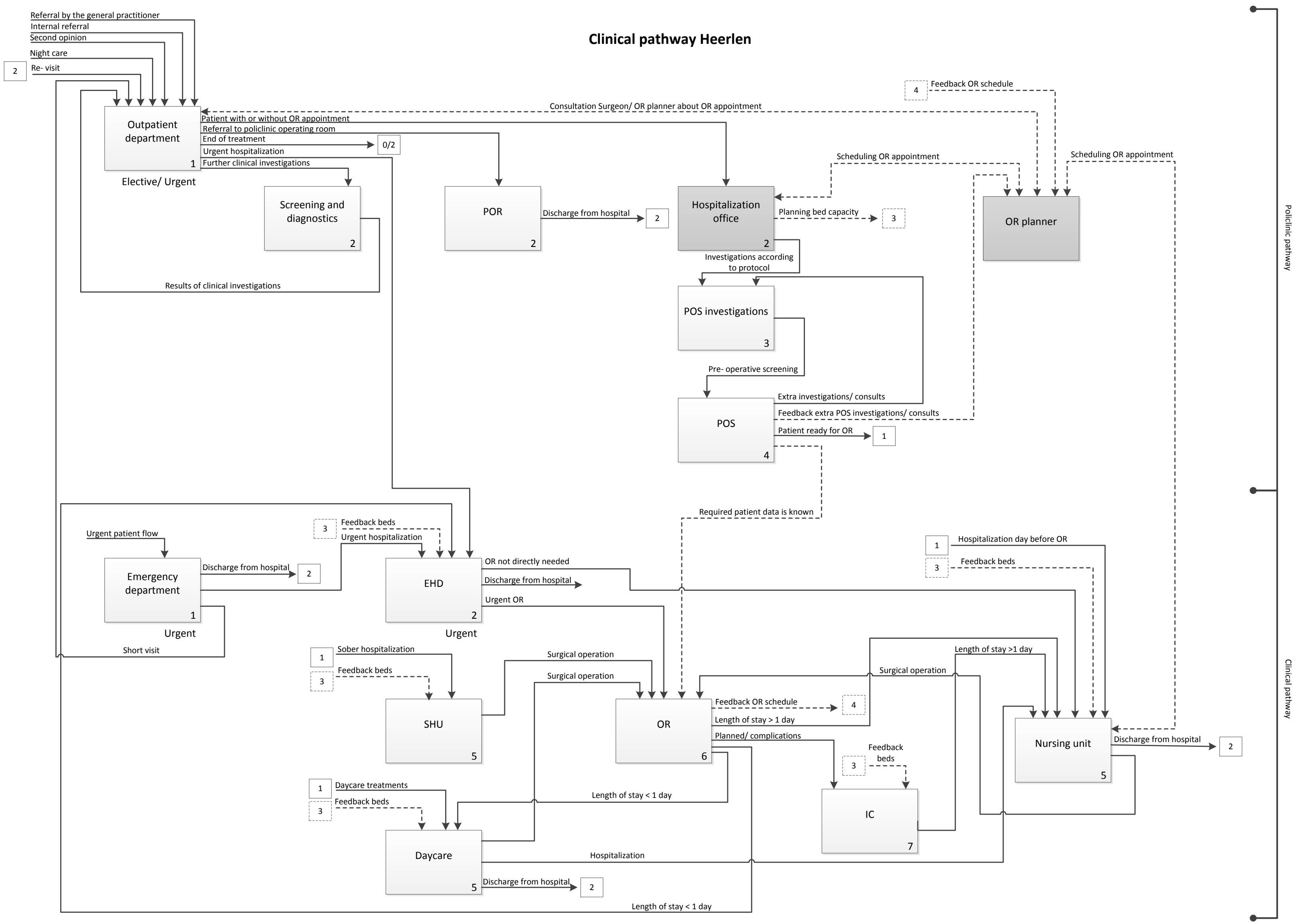


*Figure 2: Clinical pathway Heerlen*

## 3.2 The planning process

This section describes the planning process of Sittard and Heerlen. The differences in the way of planning at both locations should become clear in this section. A detailed overview of every important unit in the planning process can be found in appendix F. The planning process (Detailed version).

There are different ways in which the patient can enter the process flow, either via the outpatient department or via the emergency department. The schedule of the outpatient department is based on the surgeons planning which becomes available for three months ahead. When comparing the planning process at the outpatient department at both locations some differences can be seen.

- Patients referred by the general practitioner to the outpatient department in Sittard receive a zorgdomein number for verification principles, this is not the case when patients are referred to the outpatient department in Heerlen.

- When further investigations are needed to determine the right diagnosis, the outpatient department assistants in Sittard schedule all the appointments together with the patient. Also the appointment for re- visit at the outpatient department is scheduled. The outpatient department assistants in Heerlen send requests for those clinical investigations or other consults to the specific departments. The patient receives an appointment request for the clinical investigations or consults at home. After this the patient has to call the outpatient department to schedule an appointment for re- visit.

- The appointment for re- visit after the POR is scheduled immediately by the outpatient department assistants in Sittard. In Heerlen, the appointment for re- visit at the outpatient department is scheduled by the POR after the treatment has been completed.

When a surgical operation is needed the patient will be referred to the care planning in Sittard or to the hospitalization office in Heerlen. At both locations surgery is planned decentrally, this means that the care planning in Sittard and the OR planner in Heerlen only schedule OR appointments for the specialism surgery. The central planning in Sittard and the hospitalization office in Heerlen schedule the bed capacity for all specialism, so not only for surgery. Both locations start with the same way of working, since the OR schedule is created in collaboration with the care planning and the OR planner. After this, the way of working and planning patients becomes different.

Table 2 shows the different planning activities of the care planning and the central planning in Sittard and the hospitalization office and the OR planner in Heerlen. The combination of activities of both the care planning and the central planning, and the hospitalization office and the OR planner is the same. However, the separate entities cannot be seen as each other’s equals.

| **Sittard** | | **Heerlen** | |
|---|---|---|---|
| Care planning | Central planning | Hospitalization office | OR planner |
| • Creating the OR schedule | • Creating enough space at the nursing unit for all new hospitalizations | • Scheduling of the POS appointment and creating space for hospitalization at the nursing unit | • Creating the OR schedule |
| • Scheduling of the OR appointment together with the patient | • Taking care of urgent hospitalizations via the outpatient department or via de emergency department | • Taking care of urgent hospitalization transfers | • Scheduling of OR appointments |
| • Scheduling of OR appointments for the semi urgent patient flow | • Checking the OR schedule | • Checking the OR schedule | • Scheduling of OR appointments for the semi urgent patient flow |
| • Checking the pre- operative screening questionnaire | • Daily checking of the bed occupancy at the wards | • Daily checking of the bed occupancy at the wards | |
| • Scheduling of the POS appointment together with the patient | • Collecting the production monitoring numbers | • Arranging the OR appointment | |
| • Scheduling of appointments for investigations based on protocol before the POS appointment | • Collecting the outpatient department access times and the access times for surgical operations and daycare treatments | • Scheduling of appointments for investigations based on protocol | |
| • Checking the POS consultation hour | • Taking care of internal transfers and transfers from other hospitals | | |
| • Scheduling of POR appointments | | | |
| • Scheduling of the appointment at the pediatric department and pedagogic care department | | | |
| • Creating a balanced use of clinical beds and daycare beds | | | |
| • Providing information about the surgical operation to the patient | | | |

*Table 2: Planning activities Sittard and Heerlen*

## 3.3 Planning differences

With the use of Table 2 the differences between the planning processes with regard to the OR appointments and the beds can be outlined. More detailed information can be found in Appendix F. The planning process (Detailed version).

- When the patient needs a surgical operation the patient is referred to the care planning in Sittard or to the hospitalization office in Heerlen. The care planning schedules together with the patient the OR appointment, the POS appointment and appointments for investigations based on a protocol or other consults needed before the POS appointment can take place. The hospitalization office schedules the appointments for the investigations based on protocol and sends the hospitalization form to the OR planner. The OR planner schedules the OR appointment and sends the hospitalization form back to the hospitalization office. The patient receives a letter at home with the OR appointment and the POS appointment.

- The anesthesiologist at the POS can request for extra investigations or consults at other departments, those investigations and consults are scheduled by the care planning in Sittard and by the POS itself in Heerlen. The POS in Heerlen is responsible for the patient till the moment of surgical operation, in Sittard the surgeon remains responsible.

- In Sittard, patients for daycare treatments have the choice to either visit the POS or not. When the patient does not decide to visit the pre- operative screening, the care planning sends the patient files to the pre- operative screening (paper screening) just in case the anesthesiologist does want to examine the patient before the daycare treatment. In Heerlen, all patients, clinical and daycare, should visit the POS, there is no paper screening for the daycare patients.

- Every Thursday the OR planning is discussed for the next week. Present at this meeting in Sittard are the care planning, the central planning and the floor manager of the OR. In Heerlen, there are two separate meetings, one with the OR planner and the hospitalization office and one with the OR planner and the floor manager of the OR.

- The OR schedule is a so called white gaps planning at both locations; however, in Sittard every day 90 minutes are allowed to remain unscheduled for the urgent patient flow, this is not the case in Heerlen. Although, in Heerlen one OR is allocated to the urgent patient flow and is only used for surgical operations of this patient flow.

- The expected length of stay at the nursing unit is determined by the care planning in Sittard and by the surgeon in Heerlen.

- The care planning in Sittard should create a balanced use of clinical beds and daycare beds. In Heerlen, the OR planner only schedules patients for OR and does not take into account the division of the beds.

- The urgent patient flow can be seen as 2/5 of the total patient flow in Sittard and as 2/3 of the total patient flow in Heerlen. This is the reason why the way of planning in Heerlen is more ad hoc than in Sittard. The ad hoc way of planning makes it is not possible to work with frozen OR schedules for planned surgical operations for the next week.

- Children have to visit the pediatric department (< 1 year) and the pedagogic care department (< 18 years) before visiting the POS in Sittard. In Heerlen, children follow the same path as the other patients.

It becomes clear that the largest differences between both locations can be found in the way of planning the OR appointments and the way of dealing with the bed capacity. This provides a research opportunity, since the possibility exists that it could be more efficient to combine the planning of the OR's with the planning of the bed capacity in order to be able to view the consequences of planning on each other.

## 3.4 OR planning and bed capacity planning

The operation theatre in Sittard is available for surgery of elective patients on weekdays between 08:15 and 16:15 and in Heerlen between 08:00 and 17:00. The care planning in Sittard and the OR planner in Heerlen are allowed to plan patients in those timeslots. The amount of OR time per specialism is decided by the board every year again. This amount of OR time, together with the OR week schedule and the surgeons' planning is used to create an OR schedule. The OR planner in Heerlen and the care planning in Sittard have a meeting every three months to discuss the planning of the surgeons and the related OR schedule. When one of both locations is not able to fill some time slots, the OR planner and care planning will discuss if surgeons can be moved to other days. When all time slots are divided, the OR planner and the care planning are able to create an OR schedule divided to sub specialism/patient category for three months ahead.

In Sittard, the OR schedule is a so called white gaps planning, this means that every day 90 minutes are allowed to remain unscheduled for the urgent patient flow. Besides that 240 minutes per week are allowed to remain unscheduled for the semi- urgent patients of both the vascular surgery and the trauma surgery. Also in Heerlen, the OR schedule is not filled entirely. The white gaps are available for the urgent patient flow; however, sometimes the gaps are already filled earlier. Heerlen does have an emergent operating room available during the day, which is only used for emergency cases.

The OR appointment in Sittard is scheduled together with the patient. The OR request is filled by the surgeon. This form is used to determine; which type of surgical operation is needed, which surgeon should operate the patient and other important facts about the patient such as the need for an IC bed after surgery. The duration of the surgical operation is determined by the surgeon, there are no standard time slots per surgical operation type. The OR planner in Heerlen receives the hospitalization form from the hospitalization office and schedules the OR appointment for the patient. The OR appointment is communicated to the patient by the hospitalization office. The OR planner indicates the IC bed request at the OR program. The surgeon decides about the duration of the surgical operation. At both locations the requested operation durations are compared with already realized operation durations. When there is much difference between the expected operation durations and the more realistic ones, the requested operation duration will be changed by the care planning and the OR planner.

The care planning in Sittard and the OR planner in Heerlen are not responsible for the planning of the urgent patient flow, those patients follow the path directly to the OR which is responsible in this case. When a surgical operation is not urgent and the patient is first hospitalized at the nursing unit, the care planning and the OR planner schedule the surgical operation during the week or the same day.

The planning of the bed capacity at the nursing unit is not the responsibility of the care planning and the OR planner, this is the responsibility of the central planning in Sittard and the hospitalization office in Heerlen. The care planning in Sittard should create a balanced use of clinical beds and daycare beds.

The OR planner in Heerlen is only concerned with the planning of the operating rooms and not with the consequences of the OR planning with regard to the available beds at the nursing unit.

The central planning in Sittard and the hospitalization office in Heerlen are concerned with the patient logistics inside the hospital. Every year the subdivision of the beds per specialism is provided by the board. This scheme is divided in quarters which contain reduction weeks (holiday). The scheme is not the same for every day, because not all specialism operate every day.

Every Thursday the OR schedule in Sittard is discussed with the floor manager of the OR, with the care planning and with the central planning. When the central planning agrees with the OR schedule for the next week (Monday - Friday) based on the number of new hospitalizations, the OR schedule for the planned surgical operations will be frozen. When a semi- urgent patient has to be scheduled for surgical operation during that week, the care planning has to call the central planning to ask whether a bed is available at the nursing unit. The OR schedule for the current day till 10:00 am the next day needs to be ensured for all planned surgical operations.

The OR planner and the hospitalization office in Heerlen also discuss the OR schedule for the next week (Monday - Friday) based on the available beds in the nursing unit, every Thursday. However, the OR schedule will not be frozen for all planned surgical operations, this is not possible because of the large number of urgent patients arriving during the week. Every day before 12:00 am, the final OR schedule for the next day for planned patients should be available and is not allowed to change anymore.

The bed occupancy at the nursing units is checked much during the day. The number of dismissals and internal transfers during the day should equalize the number of new hospitalizations. The expected length of stay at the nursing unit is determined by the care planning in Sittard and by the surgeon in Heerlen. During the meeting on Thursday the feasibility of the OR planning is discussed. When problems can arise at the nursing unit of surgery, patients can be moved to other departments ("vreemdliggers") or patients are cancelled. Every day the OR planning for the next day is checked to determine whether this fits with the available beds at the nursing unit.

The outpatient department and the emergency department in Sittard have to call the central planning to inform them about an urgent hospitalization. The central planning creates space for the urgent hospitalization at the nursing unit and calls the nursing unit to inform them about the urgent hospitalization. When there is no bed available or the patient needs some further investigations before hospitalization, the patient is transferred to the observatorium. The patient should leave this department within 24 hours, either to the OR or to the nursing unit.

In Heerlen, the urgent patient flow also enters the process via the outpatient department or the emergency department. In case of an urgent hospitalization, the patient is first hospitalized at the EHD. When the patient leaves the hospital within 24 hours, the patient stays at the EHD. When the length of stay is longer than 24 hours, the hospitalization office arranges the transfer to the nursing unit. At both locations, the transfer to the OR is the responsibility of the care planning and the OR planner (not in case of direct emergency) and the transfer to the nursing unit is the responsibility of the central planning and the hospitalization office.

Section 3.4 makes a clear distinction between the OR planning and the bed capacity planning because those are separate units in Sittard and Heerlen. The research assignment is focused on the relation between the admission planning and the bed capacity, because patients with and without a surgical operation are considered. So the remainder of this thesis describes the relation between the admission planning and the bed capacity.

### 3.5 Zero measurement

The detailed analysis displayed in section 3.1 to 3.4 is based on qualitative research; however for the development of a mathematical model is it also important to start with some quantitative measurements from the current situation in Sittard and Heerlen. Those quantitative measurements are based on the bed deficit, the bed surplus and the number of wrong hospitalizations because according to the research assignment, those principles should be minimized.

The number of wrong hospitalizations in Sittard over 2014 is equal to 768 and the number of wrong hospitalizations in Heerlen over 2014 is equal to 1470. Thus in Sittard about 2 patients per day are hospitalized at another nursing unit than the nursing unit of surgery. In Heerlen, about 4 patients per day are hospitalized at another nursing unit than the surgery nursing unit. This means that in the current situation bed deficit is created every day at both locations, because when there was bed surplus a patient should not have to been hospitalized at another nursing unit than the nursing unit of the operating specialism (Appendix B.8 The allowed number of wrong hospitalizations).

The relatively high number of wrong hospitalizations per day at both locations provides enough reason to develop a mathematical model which relates the admission planning (patients planned for receiving a surgical operation and patients hospitalized without a receiving a surgical operation) to the bed capacity in order to be able to show the consequences of both on each other.

# 4. Development of the mathematical model

This chapter is structured in 4 sections. Section 4.1 provides a general model description, in section 4.2 the extensions to the models of Adan, et al., 2011 and Ma & Demeulemeester, 2013 and the choices to be made with regard to the mathematical model are displayed, section 4.3 describes the required input for the mathematical model and section 4.4 describes the actual mathematical model.

## 4.1 General model description

The focus of a model which relates the admission planning to the bed capacity is not on the over utilization, underutilization and overuse of the OR capacity. The admission planning considers both patients with an OR appointment and patients without an OR appointment. The maximum yearly assigned OR capacity for a specific specialism is used in the planning of patients to the OR schedule. The Mixed Integer Linear Programming (MILP) problem relates the admission planning to the bed capacity and the related bed capacity constraints. The objective function minimizes the bed deficit, the bed surplus and the number of wrong hospitalizations. Those objectives are determined by two decision variables which are: 1. The number of planned patients for surgical operation per patient category and surgery type and 2. The number of patients planned for hospitalization per surgery type without receiving a surgical operation.

A model which relates the admission planning to the bed capacity should consider the elective patient flow and the urgent patient flow. At the tactical level, elective patients are planned in order to obtain an efficient use of the available resources over a certain planning horizon. In order to be prepared for emergent patients arriving during the day with the possibility of interrupting the planned OR schedule, some part of the maximum available OR capacity per day should be reserved for the urgent patient flow.

Several different patient categories are considered, these categories are being homogeneous in terms of resource utilization. It is possible that a dispersion in patient categories at the OR schedule over the week and a dispersion of patients hospitalized without receiving a surgical operation has a positive influence on the bed capacity.

The aim is to hospitalize all patients in the categories related to; for example, the specialism surgery at the surgery nursing unit; however, sometimes due to unforeseen problems patients are hospitalized at the nursing unit of another specialism. Those patients are called wrong hospitalizations ("vreemdliggers"). This is something the hospital wants to avoid because wrong hospitalizations can cause bed shortage problems at other wards. In fact the bottleneck at one ward is moved to another ward.

Some patients who receive surgery are being hospitalized earlier than the OR appointment takes place. However, it is possible that there is no standard number of pre- operative days per category. Sometimes patients are first hospitalized before surgery seems needed. In this case it is also possible that surgery is not needed and after some length of stay the patient is discharged. So another division is made between the patients who do receive surgery during their length of stay in the hospital and patients who do not receive surgery during their length of stay in the hospital.

After surgery a patient of each category can be admitted to the IC or directly to the NU or DC. It is therefore important to divide the patients of each category also in clinical patients and daycare patients. All clinical surgeries and daycare surgeries are performed in the same operating rooms, which means that both surgery types should be planned in the same OR schedule.

In order to determine the capacity needed for the IC, NU and the DC, maximum capacity constraints are used. The values of the maximum capacity constraints are determined for a longer period of time.

It is important to keep the number of wrong hospitalizations as low as possible; however, creating too much bed surplus is also not the solution. So within the predetermined values for the maximum capacity constraints, the model should find a reasonable admission planning for all patients planned for a surgical operation and for all patients without a surgical operation. This model should minimize the bed deficit, bed surplus and the number of wrong hospitalizations.

It should be possible to change some important features in the model, because the model should provide insight in future situations. This makes it possible that values of some of those important features will change.

The changing features in the model are:

- The target number of elective patients to be operated
- The target number of patients to be hospitalized without receiving a surgical operation.
- The allowed number of wrong hospitalizations
- The maximum capacity at different wards
- The target percentage of occupied beds at a specific ward
- The reserved OR capacity for the urgent patient flow
- The maximum number of OR blocks
- The operating room block length and the constants for penalizing the number of wrong hospitalizations and the bed surplus.

The possibility of changing some of the important features of the model makes it possible to use the model in a flexible way.

## 4.2 Extensions to the models used in literature

The models presented in the literature review of chapter 2 by Adan, et al., 2011 and Ma & Demeulemeester, 2013 form a good starting point in the development of a mathematical model which relates the admission planning to the bed capacity. However, some concepts are not captured in both models and are therefore added to our model.

Design choices:

1. Distinction between elective patients and urgent patients.
2. Distinction between clinical patients and daycare patients.
3. OR capacity for elective patients and OR capacity for emergent patients
4. Patients receiving more than one surgical operation during their length of stay.
5. Length of stay distributions at the IC, NU and DC.
6. Patients hospitalized at the NU or DC without receiving a surgical operation.
7. Pre-operative days before the OR appointment.

The objective function consists of the bed deficit, the bed surplus and the number of wrong hospitalizations. As described earlier, the hospital wants to keep the number of wrong hospitalizations as low as possible. For this reason some constant is penalizing the number of wrong hospitalizations, this can be seen as “costs” for a wrong hospitalization.

In order to minimize the objective function to reach a minimum bed defict, bed surplus and number of wrong hospitalizations, some constraints consisting of parameters and decision variables are needed. Our model uses a list of parameters which have a fixed value and will not be changed during the search to the minimum. The decision variables used in our model can be changed during the search to the minimum and will receive a value which causes the minimum. The decision variables in our model are: *The number of patients from a patient category with a surgery type operated on a specific* *day and the number of patients hospitalized with a surgery type without receiving a surgical operation on a specific day.*

### *4.2.1 Model design choices*

Some choices need to be made with regard to the values of the input parameters and the decision variables. Those choices are related to the design choices part which should lead to an extented model of two existing models.

#### 4.2.1.1 Elective patients vs urgent patients

In our model it is important to distinguish elective and urgent patients when scheduling patients for an OR appointment. Elective patients can be planned; however, urgent patients arrive and need to be scheduled for OR immediately. For this reason, a way should be found to deal with the elective patient flow and the urgent patient flow. The urgent patient flow is therefore indicated by a parameter displaying the arrival rate for emergent patients per category on a day. This arrival rate is multiplied by the probability that an emergent patient arrives during the day and not during the night. This parameter is needed because emergent patients arriving during the day should be planned within the planned OR schedule, which means that some OR capacity need to be reserved for emergent patients. The same length of stay distribution is used for both the elective and urgent patient flow.

#### 4.2.1.2 Clinical patients vs daycare patients

The OR capacity for elective patients is used by the clinical patients and the daycare patients, for this reason our model should consider both types of patients in order to receive a complete overview of the allocated OR capacity. This is the reason why a so called surgery type is added to our model. This surgery type can be equal to 1 “clinical surgery” or 2 “daycare surgery”. Only a clinical patient, surgery type 1, can enter the process as an emergent patient, this is not the case for surgery type 2 patients.

#### 4.2.1.3 OR capacity for elective patients vs OR capacity for emergent patients

The overall OR capacity is used to plan the elective patients and to treat the emergent patients. So this makes it important to find a solution in which both types of patients have enough OR capacity to be treated. The OR capacity is therefore modelled; by using a maximum capacity of OR blocks available per day, by using the operating room block length and by using the operation duration per category and per surgery type. In our model it is important to reserve some of the assigned OR capacity for emergent patients. The reserved OR capacity for emergent patients is implemented by ensuring that the elective patients are planned within the maximum available OR capacity per day minus the time reserved for emergent patients. The reserved capacity for emergent patients is a parameter which could be set to a predetermined value, this parameter could also be changed after some while to view the differences with regard to the objective function. The last important part of the OR capacity is the fact that the sum of the operation duration of the elective patients operated during a day plus the sum of the operation duration of emergent patients operated during a day should be less than the maximum OR capacity on that day.

#### 4.2.1.4 Patients with more than one OR appointment during their length of stay

Sometimes patients receive more than one surgical operation during their length of stay at the hospital. In the calculation of the length of stay distribution such a patient should be counted once, since all those surgical operations are performed during one hospitalization period. However, in the determination of the target number of elective patients operated during some period of time, those surgical operations should be counted all. When such a patient is counted for one surgical operation and one hospitalization, the OR volume operated during some period of time will not be correct. For this reason leaving the surgical operations more than one in one hospitalization period out of scope does not provide the opportunity to draw realistic conclusions. For this reason in the calculation of the length of stay distribution, the length of stay is counted once. In the calculation of the target number of elective patients operated during a time horizon all surgical operations are counted. In the mathematical model every elective patient for surgery is seen as a new patient and receives a certain length of stay based on chances of occurrence. In reality such a patient returns to his own bed at the nursing unit and needs to recover from this surgery. This can also be seen as a new length of stay.

#### 4.2.1.5 Length of stay distributions at the IC, NU and DC

The inequalities for the DC are inspired by the inequalities for the IC and the NU which are used in our model. However, patients at the DC do not have a length of stay longer than 1 day. This means that all patients are discharged at the day of surgical operation. The day after surgical operation, there are no patients of the day before, so all beds are available again. In this case a length of stay distribution as used for the patients at the IC and NU is not needed. The length of stay of a patient at the DC is based on the average length of stay per patient category.

The length of stay distribution used at the IC and NU has a minimum of 0 hours and a maximum related to the maximum length of stay recorded on a particular ward (IC and NU) over all patient categories. The length of stay distribution is multiplied by the number of clinical patients per patient category operated during a day. The constraints related to the IC and the NU focus on both elective and urgent patients, the constraints of the DC only considers elective patients. The constraints for the IC, NU and DC should satisfy some inequalities which are related to the bed deficit and bed surplus. The maximum capacity for a ward (IC, NU and DC) on a day is multiplied by a parameter which expresses the target percentage of occupied beds on a ward per day. This parameter is added because it should be possible to use our model in a fixed or flexible way. So it is possible to allow the planning of all available beds in the total bed capacity or to use just a percentage of the total available bed capacity. When not all beds are available, the share of the total bed capacity of a specific ward used by a specialism can be displayed.

When our model is only used for the calculation of the bed shortages for one specialism, the length of stay distribution is only based on the length of stay at the department of that specialism. In this case the length of stay after surgery equal to five days does not have to mean, five days in the same order. It is possible for a patient to be hospitalized at a department of another specialism for several days. Those days are not counted for the calculation of the length of stay.

#### 4.2.1.6 Patients hospitalized at the NU or DC without receiving a surgical operation

Patients hospitalized at the NU or at the DC without receiving a surgical operation should be taken into account since those patients are occupying a clinical bed or a daycare bed for some length of stay. In order to be able to draw conclusions about the relation between the admission planning and the bed capacity also those patients should be included in a mathematical model. The implementation of the term describing the patients hospitalized at the NU or DC without receiving surgery can be done by choosing from several options.

1. The use of a target number of patients hospitalized at the NU or DC without receiving surgery during the planning horizon. In this case a variable is needed which shows the number of patients actually hospitalized on a day without receiving surgery. This option can be compared to the target number of elective patients per category with a specific surgery type operated during the planning horizon and the use of a variable which displayes the number of patients per patient category and surgery type operated on a day.

   This option is not chosen within the case study part of this report. The case study is based on the specialism surgery, for this specialism patients without receiving a surgical operation are most of time part of the urgent patient flow. For this reason those patients cannot be planned before, so for this specialism the use of a target number of patients and a related variable is not an option, because one cannot choose to either schedule them on one day or another day. However, for another specialism than the specialism surgery it could be possible that patients without receiving a surgical operation can be planned before. In this case, using a target number of patients hospitalized without receiving a surgical operation and a related variable should be the right option. So the general mathematical model uses option 1 and the model used for the case study part uses option 3.

2. The use of an operation duration equal to zero. In this case the patients without surgery are part of the elective patient group who needs to be planned for surgery, only their operation duration is equal to zero. However, in this case the same length of stay distribution is used for all patients and the patients without receiving surgery are becoming planned patients which is often not the case related to the followed path. So this option is not chosen.

3. The use of an arrival rate for the patients hospitalized without receiving surgery. This can be compared to the arrival rate for emergent patients. This option is chosen for the case study part because in this case there is no choice to make, so those patients arrive and should be hospitalized. In this way the mathematical model includes both the urgent patient flow and the patients without surgery, so a more realistic and "optimal" OR schedule of planned patients related to the NU and the DC can be created.

It is possible for patients without receiving surgery to be hospitalized at the IC; however, this is a small percentage of the total number of patients without receiving surgery so this is left out of scope.

Related to the patients at the NU and DC without receiving surgery, another choice need to be made about the subdivision of those patients. There are two options, using the same patient categories as for patients who receive surgery or only subdividing them into clinical and daycare patients (surgery type). The last option is chosen because the number of patients without receiving surgery is not that large, so another subdivision would create too small groups. Another reason is that the wards are dedicated to a specialism, so there are no separated beds available per patient category. The OR schedule is structered around those patient categories; however, these patients do not receive surgery so can be seen as one group. The length of stay distribution for the patients without receiving surgery is not the same as for patients who receive surgery. There is more variation possible in the length of stay distribution of patients without receiving surgery because the planning of those patients is sometimes possible and sometimes not depending on the specialism.

#### 4.2.1.7 Pre-operative days before OR appointment

The length of stay distribution of patients planned for OR is based on the length of stay after surgery. Some patients are hospitalized a few days earlier than the OR appointment is planned. It is possible that those pre-operative days are equal to a fixed number. However when those days vary or patients are first hospitalized without an OR request and in the end surgery is still needed, those pre-operative days cannot be seen as fixed. For this reason our model uses the length of stay of a patient receiving surgery from the day of surgery minus a maximum of 24 hours till discharge, the length of stay larger than 24 hours before surgery is added to the length of stay distribution of the patients without receiving surgery. Otherwise an assumption about the length of stay of a patient within a specific patient category after surgery cannot be made. It was also possible to leave the length of stay larger than 24 hours before OR out of scope; however, in this case the final bed occupance would not be complete. For this reason this part of the hospitalization period is added to the length of stay distribution of patients without receiving surgery.

### 4.2.2 Summary

Section 4.2.1 provides an overview of all the choices which need to be made in relation to the mathematical model. Those choices are concerned with:

- Elective patients vs urgent patients
- Clinical patients vs daycare patients
- OR capacity for elective patients vs OR capacity for emergent patients
- Patients with more than one OR appointments during their length of stay
- Length of stay distribution at the IC, NU and DC
- Patients hospitalized at the NU or DC without receiving a surgical operation
- Pre-operative days before OR appointment

It is not possible to capture all manual actions from the daily practice into a mathematical model. Our model is created to display all important actions within the planning of patients and tries to reduce the number of wrong hospitalizations ("vreemdliggers"), the bed shortages and the need of last moment arrangements at a tactical level.

## 4.3 Required input for the mathematical model

The data used for this analysis is based on the OR data and hospitalizations data of 2014 in Sittard and Heerlen. Both lists are linked to each other in order to be able to follow the patient from OR to the IC, NU or DC.

- Target number of elective patients within a patient category with a specific surgery type to be operated during the planning horizon ($T_{c,s}$).

This target number is based on averages, so the total number of patients within a patient category with a specific surgery type operated during the year 2014 is divided by x depended on the planning horizon. In this case averages are used because the data is of a historical nature and the data is used for creating tactical plans. When an operational plan should be created also a forecast of the future data is needed, for this reason historical data in this case is enough.

- Target number of elective patients with surgery type s without receiving a surgical operation to be hospitalized during the planning horizon ($T_{\cancel{OR},s}$).

This target number is based on averages, so the total number of patients with surgery type s without receiving a surgical operation hospitalized at the nursing unit or daycare unit during the year 2014 is divided by x depended on the planning horizon. In this case averages are used because the data is of a historical nature and the data is used for creating tactical plans. When an operational plan should be created also a forecast of the future data is needed, for this reason historical data in this case is enough.

- Operation duration in hours per patient category with a specific surgery type ($O_{c,s}$).

The operation duration is assumed to be deterministic because the focus of our model is not on the overrun of OR sessions. So average operation durations per patient category and surgery type are used and should be sufficient.

- Maximum length of stay recorded in IC, NU and NU, for patients without receiving OR, over all patient categories with surgery type 1 ($L^{max}_{IC(c,1)}$, $L^{max}_{NU(c,1)}$, $L^{max}_{NU(1)\ \cancel{OR}}$).

The maximum length of stay is recorded after the deletion of the outliers, and can be found by taken the maximum of all recorded lengths of stay at the IC and the NU over all patient categories with surgery type 1. For the patients at the NU without receiving OR, the maximum length of stay only depends on the surgery type. The maximum length of stay is used in the calculation of the length of stay distribution.

- Length of stay distribution of patients at the Intensive Care ($P_{IC,c,1,d}$).

A stochastic length of stay distribution is used. For all patient categories with surgery type 1 a separate length of stay distribution at the IC is calculated. The length of stay distribution is based on chances of occurence. So the percentage displayed in the distribution shows the chance for a patient within a patient category to be at the IC for several days after surgery.

- Length of stay distribution of patients at the Nursing Unit ($P_{NU,c,1,d}$).

Same calculation as the length of stay distribution of the IC. However, both LOS distributions are linked to each other. When a patient is first hospitalized at the IC, this patient should not be counted for the percentage of patients at the NU at the day of surgery. So when 10% of a patient category is hospitalized at the IC after surgery, a maximum value of 90% should be displayed at the LOS distribution of this patient category at the NU at the day of surgery. When the LOS distribution is displayed for only one specialism, five days after surgery does not have to mean, five days in the same order. This means a length of stay of five days for that specific specialism.

- Length of stay distribution of patients at the Nursing Unit without receiving surgery ($P_{NU\ \not{OR},1,d}$).

The length of stay is calculated in the same way as for the IC and NU. A separate length of stay distribution is chosen because this particular group often consist of planned/ semi-urgent hospitalizations which have a more uncertain progress than planned hospitalizations after surgery.

- Length of stay of patients at the Daycare Unit ($AVG_{DC,c,2}$).

The length of stay of patients at the DC is based on the average length of stay per patient category and surgery type 2, because all patients are discharged within one day. This means that a length of stay distribution as used at the IC and NU is too complicated for the length of stay at the DC, which makes the use of an average length of stay suitable.

- Length of stay of patients at the Daycare Unit without receiving surgery ($AVG_{DC\ \not{OR},2}$).

Also in this case, the length of stay at the DC is based on the average length of stay of all daycare patients without receiving surgery.

- Maximum capacity for the IC, NU and DC ($C_{w,d}$).

These values are sometimes allocated per specialism; however, this is not always the case. For this reason a target percentage of occupied beds is used. This provides the opportunity to use our model in a flexibel way and view the direct consequences of changes in the maximum capacity for the IC, NU and DC.

- Target percentage of occupied beds on the IC, NU and DC ($R_{w,d}$).

The target percentage is used to determine the share per specialism of the maximum not specifically allocated capactiy. So for example, the maximum IC capacity is equal to 12 beds, the target percentage is set to 0,25 which means that 3 beds can then be used by that specific specialism. The target percentage is determined by trial and error because some capacities are not speficied per specialism.

- Reserved OR capacity in hours for emergent patients per day ($E_1$).

When some OR capacity is reserved for the emergent patients every day, no planned patients have to be cancelled because of an emegernt patient. The reserved capacity is determined by the hospital under investigation and by trial and error, because the determined value by the hospital does not have to be the best optimal value for the mathematical model.

- Maximum capacity of OR blocks on a day ($C_{OR\ block,d}$).

Every day some predetermined number of OR blocks is available. This is the maximum OR capacity for that particular day. Elective patients and emergent patients arriving during the day should be planned within this OR capacity.

- Operating room block length ($L_{OR\ block}$).

The operating room block length is displayed in hours. Often an operating room block can be seen as half of a day. So when a day contains eight hours, the operating room block length is equal to four hours.

- Arrival rate of emergent patients within a patient category on a day ($\beta_{c,d}$).

The emergent patients arrive at a certain rate on a specific day. The arrival rates are displayed per patient category and per day of the week. This means that every day of the week has its own chance on emergency arrivals which can differ per day of the week. The arrival rates should apply for every week within the planning horizon.

- Probability that an emergent patient arrives during the day and not during the night ($q_d$).

This value is set to a specific percentage which is calculated using the data of the emergency arrivals. The arrival rates for one week should apply for every week within the planning horizon.

- Constant for penalizing the number of wrong hospitalizations and the surplus ($b_1 and\ b_2$).

In cooperation with the hospital under investigation is decided to use a maximum value of 100 which will be divided between the number of wrong hospitalizations and the surplus. In this way the trade off between the number of wrong hospitalizations and the surplus can be displayed. A high number of wrong hospitalizations is seen as worse than a high surplus. So b1 can be set to for example, 70 and b2 is then set to (-) 30.

- Allowed number of wrong hospitalizations ($Hz$).

This number is derived from the historical data and is changed when needed and possible. In this way the tradeoff between the maximum use of the OR capacity and the bed deficit related to the number of wrong hospitalizations can be shown.

- Maximum bed capacity at NU with wrong hospitalizations included ($C_{NU,d,hz}$)

The maximum bed capacity at the NU with the wrong hospitalizations included depends on the maximum capacity at the NU of a specific specialism together with the allowed number of wrong hospitalizations (spare capacity).

## 4.4 The mathematical model

The mathematical model is formulated as a mixed integer linear program.

<u>Parameters</u>

| | |
|---|---|
| $N$ | Set of patient categories |
| $c$ | Patient category index, c=1,….,N |
| $D$ | Set of days in the cycle planning horizon |
| $d$ | Day index |
| $S$ | Set of surgery types |
| $s$ | Surgery type index, s= 1,2<br>1= “Clinical surgery”<br>2= “Daycare surgery” |
| $T_{c,s}$ | Target number of elective patients of category c with surgery type s to be operated during the planning horizon |
| $T_{\cancel{OR},s}$ | Target number of elective patients with surgery type s without receiving a surgical operation to be hospitalized during the planning horizon |
| $O_{c,s}$ | Operation duration in hours for a patient of category c with surgery type s |
| $W$ | Set of wards |
| $w$ | Ward index, $w \in IC(c), NU(c), DC(c)$ |
| $L_{IC(c,1)}^{max}$ | Maximum length of stay recorded in IC over all patient categories with surgery type 1 |
| $L_{NU(c,1)}^{max}$ | Maximum length of stay recorded in NU over all patient categories with surgery type 1 |
| $L_{NU(1)\ \cancel{OR}}^{max}$ | Maximum length of stay recorded in NU for all patients with surgery type 1 without receiving OR |
| $P_{IC,c,1,d}$ | Probability that a patient from category c with surgery type 1 is at the IC unit for a period of d days d=0,1,2,…, $L_{IC(c)}^{max}$ |
| $P_{NU,c,1,d}$ | Probability that a patient from category c with surgery type 1 is at the Nursing Unit for a period of d days d=0,1,2,…, $L_{NU(c)}^{max}$, after surgery |
| $P_{NU\ \cancel{OR},1,d}$ | Probability that a patient with surgery type 1 is hospitalized at the Nursing Unit without receiving a surgical operation for a period of d days d=0,1,2,…, $L_{NU(c)\ \cancel{OR}}^{max}$ |
| $AVG_{DC,c,2}$ | Average period of time (hours) that a patient from category c with surgery type 2 is at the Daycare department after surgery |

| | |
|---|---|
| $AVG_{DC\ \cancel{OR},2}$ | Average period of time (hours) that a patient with surgery type 2 is at the Daycare department without receiving surgery |
| $C_{w,d}$ | Maximum capacity for ward w on day d<br>(expressed the number of beds for IC(c), NU(c) and DC(c)) |
| $R_{w,d}$ | Target percentage of occupied beds on ward w on day d |
| $E_1$ | Reserved OR capacity in hours for emergent patients with surgery type 1 (equal for every day) |
| $C_{OR\ block,d}$ | Maximum capacity of OR blocks on day d |
| $L_{OR\ block}$ | Operating room block length (hours) |
| $\beta_{c,d}$ | Arrival rate for emergent patients of category c on day d |
| $q_d$ | Probability that an emergent patient arrives during the day d and not during the night |
| $b_1$ | Constant for penalizing the number of wrong hospitalizations |
| $b_2$ | Constant for penalizing the surplus |
| $Hz$ | Allowed number of wrong hospitalizations |
| $C_{NU,d,hz}$ | Maximum bed capacity at NU with wrong hospitalizations included |

Decision variables

$X_{c,s,d}$ Number of patients from category c with surgery type s to be operated on day d; with c=1,…,N, s=1,2 and d=1,…, D

$Y_{\not{OR},s,d}$ Number of patients with surgery type s without receiving a surgical operation to be hospitalized on day d; with s=1,2 and d=1,…, D

Formulas in the objective function

$\delta^{-}_{wd}$ Bed deficit of ward w on day d; with $w \in IC(c), NU(c), DC(c)$, c=1,…,N and d=1,….,D

$$\rightarrow \delta^{-}_{wd} = \max\left(EX(occupied\ beds)_{w,d} - \left(C_{w,d} \cdot R_{w,d}\right), 0\right) \qquad If\ w = NU; C_{NU,d,hz} \qquad (4.1)$$

$\delta^{+}_{wd}$ Bed surplus of ward w on day d; with $w \in IC(c), NU(c), DC(c)$, c=1,…,N and d=1,….,D

$$\rightarrow \delta^{+}_{wd} = \min\left(EX(occupied\ beds)_{w,d} - \left(C_{w,d} \cdot R_{w,d}\right), 0\right) \qquad (4.2)$$

$\delta^{+}_{NUhz,d}$ Maximum daily accepted number of wrong hospitalizations

$$\rightarrow \delta^{+}_{NUhz,d} = \max(EX(occupied\ beds)_{NU} - (C_{NU,d} \cdot R_{NU,d}),0) \qquad (4.3)$$

*Objective function:*

$$min \sum_{w\in W}\sum_{d\in D} \delta_{wd}^{-} + b_2\delta_{wd}^{+} + b_1\,\delta_{NU,hz,d}^{+}$$

$s.t$

$$\sum_{d\in D} X_{c,s,d} = T_{c,s} \qquad \forall c \in N, \forall s \in S \tag{4.4}$$

$$\sum_{d\in D} Y_{\cancel{OR},s,d} = T_{\cancel{OR},s} \qquad \forall c \in N, \forall s \in S \tag{4.5}$$

$$\sum_{c\in N}\sum_{s\in S} O_{c,s}\,X_{c,s,d} \le \left(C_{OR\ block,d}\cdot L_{OR\ block}\right) - E_1 \qquad \forall d \in D \tag{4.6}$$

$$\sum_{c\in N}\sum_{s\in S} O_{c,s}X_{c,s,d} + \sum_{c\in N}\sum_{s\in S} O_{c,s}q_{c,d}\beta_{c,d} \le C_{OR\ block,d}\cdot L_{OR\ block} \qquad \forall d \in D \tag{4.7}$$

$$\sum_{c\in N}\sum_{j=0}^{L_{IC(c,1)}^{max}} P_{IC,c,1,j}X_{c,1,d-j} + \sum_{c\in N}\sum_{j=0}^{L_{IC(c,1)}^{max}} P_{IC,c,1,j}\beta_{c,d-j} \quad \left.\begin{matrix} \le \left(C_{IC,d}\cdot R_{IC,d}\right) + \delta_{IC,d}^{-} \\ \ge \left(C_{IC,d}\cdot R_{IC,d}\right) - \delta_{IC,d}^{+} \end{matrix}\right\} \quad \forall d \in D \tag{4.8}$$

$$\sum_{j=0}^{L_{NU(1)\cancel{OR}}^{max}} P_{NU,\cancel{OR},1,j}\,Y_{\cancel{OR},1,d-j} + \sum_{c\in N}\sum_{j=0}^{L_{NU(c,1)}^{max}} P_{NU,c,1,j}X_{c,1,d-j} + \sum_{c\in N}\sum_{j=0}^{L_{NU(c,1)}^{max}} P_{NU,c,1,j}\beta_{c,d-j}$$

$$\left.\begin{matrix} \le \left(C_{NU,d}\cdot R_{NU,d}\right) + \delta_{NU\ hz,d}^{+} \\ \le \left(C_{NU,d,hz}\cdot R_{NU,d}\right) + \delta_{NU,d}^{-} \\ \ge \left(C_{NU,d}\cdot R_{NU,d}\right) - \delta_{NU,d}^{+} \end{matrix}\right\} \quad \forall d \in D \tag{4.9}$$

$$AVG_{DC,\cancel{OR},2}Y_{\cancel{OR},2,d} + \sum_{c\in N} AVG_{DC,c,2}X_{c,2,d} \quad \left.\begin{matrix} \le \left(C_{DC,d}\cdot R_{DC,d}\right) + \delta_{DC,d}^{-} \\ \ge \left(C_{DC,d}\cdot R_{DC,d}\right) - \delta_{DC,d}^{+} \end{matrix}\right\} \quad \forall d \in D \tag{4.10}$$

$$X_{c,s,d} = 0 \ and \ X_{c,s,d+1} = 0, \ \ d = 6 + 7(j-1); \ \ j = 1, \dots, \left({}^{D}\!/_{7}\right); \ \ c = 1, \dots, N \tag{4.11}$$

$$X_{c,s,d} \in \{0,1,2,\dots,\}, \qquad Y_{\cancel{OR},s,d} \in \{0,1,2,\dots,\}, \qquad \forall c \in N, \ \ \forall s \in S, \ \ \forall d \in D \tag{4.12}$$

### *4.4.1 The objective function*

The objective function minimizes the total expected bed shortage and the total expected bed surplus over all wards (IC(c), NU(c), DC(c)) per day by determining the variables $X_{c,s,d}$ and $Y_{\cancel{OR},s,d}$. It is important to satisfy some constraints without much deviation from the target percentage of occupied beds on a ward per day. The number of wrong hospitalizations at the NU per day is also minimized in the objective function, because the aim is to hospitalize almost all patients at the nursing unit of the operating specialism. For this reason the use of the maximum daily accepted number of wrong hospitalizations is penalized by the constant b1.

(4.1) The calculation of the bed deficit is based on the expected number of occupied beds calculated in (4.8 – 4.10), minus the maximum available bed capacity at a specific ward multiplied by the target percentage of occupied beds. The bed deficit is displayed by the maximum of the outcome of the calculation and zero. When the nursing ward is considered, the maximum available bed capacity is equal to the maximum available bed capacity with the allowed number of wrong hospitalizations included. The reason for this is that only at the nursing unit wrong hospitalizations are considered.

(4.2) The calculation of the bed surplus is based on the expected number of occupied beds calculated in (4.8 – 4.10), minus the maximum available bed capacity at a specific ward multiplied by the target percentage of occupied beds. It is important to understand that in this case the maximum available bed capacity at the nursing unit without the allowed number of wrong hospitalizations should be taken into account. When the number of allowed wrong hospitalizations is taken into account, the bed surplus is not only based on the nursing unit of that particular specialism. The bed surplus is displayed by the minimum of the outcome of the calculation and zero. This means that the bed surplus is equal to zero or a negative number. The objective function minimizes the bed deficit (positive number or zero), bed surplus (negative number or zero) and number of wrong hospitalizations (positive number or zero), and chooses a negative number above a positive number. For this reason a constant (b2) penalizing the bed surplus equal to a negative number is needed to create a positive number in the calculation of the objective function. Otherwise creating much bed surplus causes a low minimum and is more attractive than creating a low number of wrong hospitalizations or a low bed deficit.

(4.3) The calculation of the number of wrong hospitalizations is based on the expected number of occupied beds at the nursing unit calculated in 4.9, minus the maximum available bed capacity at the nursing unit multiplied by the target percentage of occupied beds. The number of wrong hospitalizations is displayed by a positive number equal to zero or to the outcome of the calculation.

### *4.4.2 Explanation of the constraints 4.4 to 4.12*

(4.4) The left side of equation 4.4 shows the total number of patients of category c with surgery type s to be operated on day d of day cycle D. This should be equal to the right side of equation 4.4 which represents the target patient throughput per category c with surgery type s.

(4.5) The left side of equation 4.5 shows the total number of patients with surgery type s without receiving a surgical operation to be hospitalized on day d of day cycle D. This should be equal to the right side of equation 4.5 which represents the target patient throughput with surgery type s for patients without receiving a surgical operation.

(4.6) The operation duration in hours for a patient of category c with surgery type s multiplied by the total number of patients from category c with surgery type s operated on day d represent the first term of equation 4.6. This term should be equal or less to the second term of equation 4.6 which describes the maximum capacity of OR blocks available on day d multiplied by the operating room block length. Some part of the available operation time of day d is reserved for emergent patients. This means that the total available capacity of OR hours per day d should be decreased by the reserved capacity in hours for emergent patients with surgery type 1 on a day. The reserved capacity for emergent patients is equal for every day.

(4.7) The first part of the left side of equation 4.7 describes the expected utilization of the OR by the elective patients and the second part of the left side of equation 4.7 describes the expected utilization of the OR by the emergent patients. The left part should satisfy the right part of equation 4.7 which shows the maximum capacity of OR blocks on day d multiplied by the operating room block length.

The equations 4.8, 4.9 and 4.10 use the subscript d-j in $X_{c,s,d-j}$ and in $Y_{\cancel{OR},1,d-j}$ which should be treated modulo D: day 0 is the same as day D, day -1 is the same as day D-1 and so on. Day zero can be seen as the day of surgical operation.

(4.8) Equation 4.8 only holds for surgery type s equal to 1, because only the clinical patients are hospitalized at the IC when needed. This equation calculates the expected number of IC beds. The first term of equation 4.8 describes the probability that a patient from category c with surgery type 1 stays at the IC unit for a period of d days with a maximum length of $L_{IC(c)}^{max}$. This term should be multiplied by the number of patients of category c with surgery type 1 operated during day d-j. The second term of equation 4.8 describes the same as the first term only for the emergent patients. Both terms should satisfy the two inequalities on the right side of equation 4.8. Both inequalities shows the maximum capacity of the IC on day d multiplied by the target percentage of occupied beds on the IC on day d related to the bed deficit and the bed surplus.

(4.9) Equation 4.9 calculates the expected number of beds at the nursing unit. The first term on the left side shows the patients which are hospitalized at the nursing unit without receiving a surgical operation. The length of stay distribution for those patients is not the same as for patients with an OR appointment. In this case all patient categories are taken together, so only surgery type s equal to 1 is important, because the ward is not divided according to patient categories. The second term shows the length of stay distribution of patients of category c with surgery type 1 after receiving surgery, and the third term shows the length stay distribution for emergent patients of category c and surgery type 1 after surgery. Those three terms should satisfy three inequalities. The first term shows the maximum available capacity at the nursing unit multiplied by a target percentage of occupied beds at the NU related to the number of wrong hospitalizations on day d. The second term shows a term which includes the maximum capacity of the NU on day d and the maximum daily number of accepted wrong hospitalizations multiplied by a target percentage of occupied beds at the NU on day d related to the bed deficit of the NU on day d. This means that it is possible to hospitalize a patient at another nursing unit than the nursing unit of surgery. The third inequality shows the maximum capacity of the NU on day d which is multiplied by the target percentage of occupied beds on the NU on day d related to the bed surplus of the NU on day d.

(4.10) Equation 4.10 is used to calculate the expected number of daycare beds. The first term describes the average length of stay of patients with surgery type 2 from all categories together, which are hospitalized at the daycare unit without receiving surgery. The second term shows the average length of stay for patients with category c and surgery type 2 hospitalized at the daycare unit after surgery. Both terms on the left should satisfy the inequalities on the right. The first inequality shows the maximum capacity of the DC on day d which is then multiplied by the target percentage of occupied beds on the DC on day d related to the bed deficit of the DC on day d. The second inequality is the same as the first only related to the bed surplus of the DC on day d.

(4.11) On weekends operating rooms are dedicated only to emergency patients which means that equation 4.11 is needed to ensure that elective patients are planned for surgery during day 1-5 and day 8-12. The days 6,7 and 13,14 are considered as weekend.

(4.12) In order to minimize the expected bed shortage over all wards (IC, NU and DC), our mathematical model can be used by minimizing the objective function (4.1 - 4.3) subject to the constraints (4.4) to (4.11) and the integrality constraints (4.12).

# 5. Validation and verification

This chapter describes in section 5.1 the general principles behind validation and verification. In section 5.2 the validation process is described and in section 5.3 the verification process which is used to test the mathematical model is further explained. For the validation and the verification of the mathematical model, data sets provided by the hospitals under investigation are used.

## 5.1 General principles validation and verification

It is always difficult to determine the difference between validation and verification. According to Serendipity, (2010) validation and verification can be defined as follow:

- Validation: Are we building the right system?
- Verification: Are we building the system right?

In more detail, validation checks whether the system meets the customer's actual needs, while verification checks whether the system is well engineered and error free. Verification does not ensure that the system is useful.

Validation is concerned with activities such as; requirements modelling, prototyping and user evaluation, while verification is concerned with; testing, inspection, design analysis and specification analysis. Validation can be seen as a subjective process and verification as an objective process (Serendipity, 2010).

## 5.2 Validation

The validation of the mathematical model is ensured by two weekly meetings with the employee business control from the location Sittard and the manager capacity management from the location Heerlen (supervisors). Every two weeks the progress made was discussed and feedback provided by both supervisors was used in building a prototype of the mathematical model in MS Excel. The choice to build the mathematical model in MS Excel using the Excel solver is made because in this way the model can be used easily within both hospitals. In this way the mathematical model becomes useful from the Zuyderland MC. At the end of September the last meeting with the employee business control from the location Sittard and the manager capacity management from the location Heerlen took place. During this meeting, a working prototype of the mathematical model was shown. Both supervisors were very enthusiastic about the capabilities of the model and had many ideas about the usefulness of the model in practice.

## 5.3 Verification

The verification of the mathematical model is ensured by testing the model with historical data sets provided by the hospitals. Before the mathematical model can be tested, the data sets should first be analyzed. The data analysis part can be found in section 5.3.1. Section 5.3.2 describes the values of the input parameters to test the mathematical model. The mathematical model is tested with the use of these values which represent the current situation at both hospitals. Section 5.3.3 provides an overview of the testing phase for Sittard and Heerlen.

### *5.3.1 Data analysis*

The hospital information system used in Sittard and in Heerlen before the merger was not the same at both locations. In Sittard, the information system SAP is used which is implemented in Heerlen as well after the merger. It is important to process the patient data in the same way at both locations since the clinical pathway of a patient can start at one location and can end at the other location. This means that the patient data should be transferred between both locations of the Zuyderland MC.

The data used to test the mathematical model is based on the data about the surgical operations and about the hospitalizations of the specialism surgery. The patient data of the year 2014 is used from Sittard and Heerlen. In 2014 both hospitals were not merged by then which means that the data lists did not have the same format. The data list about the surgical operations and the data list about the hospitalizations were separate lists, so to be able to follow one patient from the OR to the IC, NU or DC both data lists should be linked.

The data lists of Sittard are linked according to the "zorggeval" (ZGV) number; however, it is possible that this number changes somewhere between the OR and IC, NU or DC. When this number changes a link between both data lists cannot be found. In this case, this patient has to be searched by hand in SAP, to find the right patient data. The data lists of Heerlen are linked according to a patient number, this number was available in both lists. The OR data list is not divided according to patient categories. The subdivision in patient categories is based on a profile list with DOT (DBC's ((Diagnose behandeling code) op weg naar transparantie) codes. The information about the DOT codes cannot be found in SAP, this data is stored in some financial system. With the use of this data, patient categories could be distinguished.

The same way of processing the data is used in Sittard and in Heerlen. In order to create a data list which is suitable for testing our mathematical model, some choices need to be made. In the original OR data list, 3272 surgical operations are listed for Sittard and 5911 surgical operations are listed for Heerlen.

- Same ZGV number or patient number in the OR data and same OR date.

The ZGV number and patient number are unique numbers and only used for one patient. When a surgical operation is performed by two specialism or by two surgeons, the surgical operation is registered twice in the OR data list. When those cases are not removed, the surgical operation will be counted twice in the calculation of the OR volume in a year. This is not right because the surgical operation is performed during one OR session and by using one operating room. So by using the data to draw conclusions about the OR capacity and other capacity constraints, those surgical operations should be counted once.

50 surgical operations were removed from the OR data list in Sittard because of the reason explained above and 103 surgical operations were removed from the OR data list in Heerlen for the same reasons.

- Patients with more than one OR during the same hospitalization period.

It is possible that a patient is operated more than once during the same hospitalization period. During the linking of the OR data list with the hospitalizations data list based on the ZGV number and patient number, every OR is linked to a hospitalization period with the same ZGV number or patient number. When the same ZGV number or patient number is counted more than once in the OR data list, the same hospitalization period and duration is added to both surgical operations.

It is also possible, at the location Sittard, that the ZGV number in the OR data list changes during the same hospitalization period. The hospitalizations data list contains a corrected ZGV number which ensures that the ZGV number does not change between the hospitalization date and the date of discharge. When no link is found between the ZGV number at the OR data list and the hospitalizations data list, those patients have to be searched in SAP by hand. In this case, it is possible that patients with a different ZGV number at the OR, do have a hospitalization date and duration which is the same for both surgical operations. So by only filtering the linked OR and hospitalizations data list based on ZGV number is not enough to find all those cases. For this reason the linked data list is also filtered on surname to find all the cases for which the OR date differs and for which the hospitalization date and duration are the same.

For the calculation of the length of stay distribution at the nursing unit, it is not right to count the same hospitalization period twice or more, because this LOS period is based on one patient. However, deleting the surgical operations with the same hospitalization date and duration is also not right, because than the yearly OR volume will not be correct anymore. For this reason is chosen to remove all the data about the hospitalization for the surgical operations more than one during the same hospitalization period. Those cases are indicated with #OR instead of the hospitalization date. So the hospitalization period for this patient is counted once in the calculation of the length of stay distribution and the surgical operations with their specific data are counted separate and are not removed. As described in chapter 4, patients with more than one OR are treated by the mathematical model as new patients and receive a new length of stay after surgery.

In Sittard 109 patients had more than one OR appointment during the same hospitalization period and in Heerlen this number of patients was equal to 236.

- Registration errors in the operation durations

The operation duration is calculated in hours. In many cases in Sittard the end time of the surgical operation is not registered and is therefore not counted in the calculation of the average operation durations. The surgical operations itself are counted, only their actual duration cannot be used because of incompleteness. In some cases in Heerlen, the OR duration is also not registered well since the duration is sometimes less than one minute. To receive a realistic average operation duration the choice is made to remove all incomplete cases and all cases with an operation duration less than 0,10 hour which equals six minutes.

In Sittard 211 cases were incomplete or consist of registration errors and in Heerlen 276 cases were incomplete or not registered well.

- Patients operated by the specialism surgery, with some LOS at the surgery IC/NU and some LOS at IC/NU of other specialism.

After surgery patients are hospitalized at the IC or directly at the nursing unit of surgery. During the length of stay at the IC or the nursing unit, it is possible that patients are transferred to nursing units of other specialism and have some length of stay under that specialism. In order to be able to draw right conclusions about the expected number of IC beds and NU beds for surgery, only the length of stay under the specialism surgery is counted.

The hospitalizations data list is a so called “patient movement” list, which means that every movement the patient makes during his/her length of stay is registered. It is therefore possible to calculate the length of stay period for surgery only.

- Patients operated by the specialism surgery without a hospitalization period for surgery.

Sometimes patients are operated by the specialism surgery but are not hospitalized at the surgery nursing unit after surgery. When those patients are counted in the OR volume, those patients are expected to be hospitalized at the nursing unit of surgery in the mathematical model. This would provide incorrect conclusions about the expected number of beds needed at the nursing unit of surgery.

It is also possible that patients are hospitalized at the IC after surgery but not at the nursing unit of surgery. The data lists of Heerlen consisted of an IC duration which did not have to be for surgery only, the IC duration provided was a total duration and not specified per specialism. So in this case it is possible that a patient is hospitalized at the IC after surgery and after the IC period hospitalized for another specialism than surgery. This is often the case for emergent patients. The data lists of Sittard consisted of IC durations which were only under the specialism surgery.

So patients which are operated under the specialism surgery and not hospitalized for the specialism surgery are indicated by x instead of the hospitalization date and patients which are hospitalized at the IC under the specialism surgery and not at the NU under specialism surgery are indicated by xx instead of the hospitalization date. Patients indicated by x are chosen to be out of scope and patients indicated by xx are chosen to be counted as well for the OR as for the IC.

In Sittard 60 patients were indicated by x and no patients were indicated by xx. In Heerlen 156 patients were indicated by x and 46 patients were indicated by 60.

- Patients which start their LOS at the observatorium or at the EHD.

The urgent patient flow enters the process via the emergency department. After the emergency department patients are hospitalized at the observatorium in Sittard or at the EHD in Heerlen. Patients can leave the observatorium within several hours or are transferred to the nursing unit. From the moment that the patient is hospitalized at the nursing unit till discharge, the specialism is known. This means that at the observatorium patients cannot be indicated by specialism. So the length of stay used in the length of stay distribution calculated for the specialism surgery, only uses the length of stay at the nursing unit of surgery. This means that the length of stay at the observatorium is removed from the total length of stay. Also the hospitalization date is adjusted to the first moment the patient occupies a clinical bed at the nursing unit of surgery.

Patients with only a length of stay at the observatorium after surgery or before surgery are indicated by OBSERV instead of the hospitalization date. Those patients are not counted in the OR volume, since those patients are not hospitalized at the nursing unit of surgery. 158 patients are not counted in the OR volume since no hospitalization period at the nursing unit of surgery was registered.

Patients hospitalized at the EHD after the emergency department in Heerlen, can be indicated by specialism. For this reason the length of stay starts at the EHD in Heerlen.

- Clinical patients vs daycare patients

The data in the OR data list and the hospitalization data list are of financial nature. This means that when a patient has a length of stay less than 24 hours, a patient is seen as a daycare patient. From a logistic point of view, a patient is a clinical patient when such a patient has occupied a clinical bed during his/her length of stay. The same holds for a daycare patient, who can be seen as a daycare patient when the patient has occupied a bed at the daycare department. The mathematical model uses the logistic point of view and divides the patients into clinical patients and daycare patients based on the occupied bed. For this reason some surgery types are changed from daycare into clinical.

- Patients hospitalized earlier than the OR appointment is planned

Sometimes patients are hospitalized earlier (day before) than the OR appointment is planned because of personal reasons. However, it is also possible that patients are first hospitalized without a planned OR appointment. In this case, the possibility exists that patients do receive a surgical operation or do not receive a surgical operation. Both groups of patients are occupying a clinical bed for some length of stay. In order to provide a realistic overview of the hospitalization period after surgery, the length of stay before surgery should be removed from the total length of stay.

The possibility exists that a patient is hospitalized the day before OR, the choice is therefore made to remove the length of stay larger than 24 hours from the total length of stay. The length of stay before OR should then be checked on specialism, because only the length stay under the specialism surgery should be counted. So it is also important to add the right hospitalization date, because the length of stay before OR is added to the patients without receiving OR and the hospitalization date is important for the calculation of the arrival rates for the patients without receiving OR (more information in section 5.3.2).

In Sittard 966 patients did not receive a surgical operation and 107 patients were hospitalized earlier than 24 hours before the OR appointment. In Heerlen 2270 patients were hospitalized without receiving a surgical operation and 490 were hospitalized earlier than 24 hours before the OR appointment.

- Patients with a clinical LOS and daycare LOS

In Sittard the possibility exists that a patient has a length of stay at the daycare unit and the nursing unit. This is also possible in Heerlen; however, the data set from Heerlen does not show those patients. In this case it was unclear whether the surgical operation should be counted as a daycare surgery or a clinical surgery. The other problem is that counting the patient for the daycare hospitalization and for clinical hospitalization is wrong because then the patient is counted twice at the same moment. Because of the fact that this data is not available in the data set of Heerlen, one chooses to count a patient as daycare when the length of stay at the nursing unit is less than 24 hours and count a patient as clinical when the length of stay at the nursing unit is more than 24 hours. The length of stay at the department which is not chosen as a surgery type is removed.

56 patients were registered with a length of stay at the daycare department and at the nursing unit.

- Verification of unclear data results

After the data analysis was completed, the average operation durations in Sittard appeared to be 1,5 times as large as the average operation durations in Heerlen. This could not be right, because the specialism surgery is merged much earlier than the complete merger of both hospitals was planned. For this reason, the same surgeons are operating patients in Sittard and in Heerlen. During a conversation with the industrial engineer in Heerlen, the average number of elective patients to be operated during two weeks and the number of OR blocks used in the mathematical model were right. So our conclusion was that the start and end times of the surgical operations provided in the data set of Sittard were not the same as the start and end times of the surgical operations provided in the data set of Heerlen. This assumption was confirmed by Business Intelligence department in Heerlen which provided the data. The start and end times of the real surgical operation were provided and not the time a patient was occupying the operating room. Since the mathematical model uses a logistics point of view, the time a patient is occupying the operating room is needed in the calculation of the OR occupancy. Also the number of wrong hospitalizations in two weeks was checked twice, to be sure that conclusions which will be drawn with regard to the number of wrong hospitalizations are correct.

After the corrections to the data sets of Sittard and Heerlen described above are implemented and the outliers in the hospitalizations data are removed and replaced (appendix A. Outliers), the data sets can be used to test our mathematical model.

### *5.3.2 Values of the input parameters*

After completing the data analysis phase it is possible to calculate the values of the input parameters used in the mathematical model for Sittard and Heerlen. Our mathematical model is tested with the use of the OR data and hospitalizations data of 2014 at the location Sittard and at the location Heerlen. The data used is only based on the specialism surgery. First some model characteristics which apply to both locations are described.

In this case, four patient categories are used.

- c=1 Onco, long, gastroint. surgery
- c=2 Vaat
- c=3 Trauma
- c=4 Algemeen

The planning horizon is chosen to be two weeks based on the OT planning which shows a cycle of two weeks. So the set of days in the planning horizon is equal to 14 and the day index runs from d=1 to d=14. The surgery types are already indicated in section 4.4, s=1 for clinical surgery and s=2 for daycare surgery. Our mathematical model is based on the IC, NU and DC as indicated in section 4.4. The target percentage of occupied beds on a specific ward are set to 1 as an initial condition. In consultation with the supervisors in both hospitals is decided to divide the value 100 over constant b1 and constant b2. For the initial conditions, b1 is set to 70 and b2 is set to -30 (surplus minimization).

When our mathematical model is solved for the planning horizon of two weeks without beds occupied at the IC and NU in the beginning, the results are not matching with the hospital conditions. For this reason the length of stay distribution is calculated till the moment of discharge for all patients operated and arrived during the two weeks in the planning horizon. So the expected number of beds occupied on day 15 are added to the expected number of occupied beds at day 1 and so further. At day 14, the expected number of occupied beds at day 28 are added to the expected number of occupied beds at day 14. By using this method, the mathematical model does not start with an empty hospital.

Another important aspect with regard to the specialism surgery is the treatment of the patients without receiving a surgical operation. Our mathematical model treats those patients the same as patients who do receive a surgical operation; however as described in section 4.2.1.6, the case study is based on the specialism surgery and patients without receiving a surgical operation are most of the time part of the urgent patient flow. This means that those patients cannot be planned before, so for the specialism surgery the use of a target number of patients and a related variable is not an option. There is no choice to either schedule those patients on one day or another day. For this reason the use of an arrival rate like the arrival rate used for emergent patients would be more suitable. This means that the mathematical model is changed at some points. An arrival rate $h_{\not{OR},s,d}$ is added to the mathematical model. The calculation of the arrival rate for patient without receiving a surgical operation is the same as for the arrival rate of the emergent patients. The arrival rate is calculated for both surgery types 1 and 2. The parameter $T_{\not{OR},s}$ is deleted from the mathematical model. Also the decision variable $Y_{\not{OR},s,d}$ is not needed anymore and equation 4.5 in the mathematical model is also no longer needed. The first parts of equations 4.9 and 4.10 are changed in $\sum_{j=0}^{L_{NU(1)-\not{OR}}^{max}} P_{NU,\not{OR},1,j}\, h_{\not{OR},1,d-j}$ and $AVG_{DC,\not{OR},2} h_{\not{OR},2,d}$. With these changes it is possible to use our mathematical model for the specialism surgery.

The remainder of this section describes the unique model characteristics of Sittard and Heerlen, the calculations behind the values displayed in section 5.3.2.1 and 5.3.2.2 can be found in Appendix B. Calculations.

#### *5.3.2.1 Unique model characteristics of Sittard*

Table 3 shows for each patient category; the target number of elective patients within surgery type 1 and 2 to be operated during the planning horizon of 2 weeks, the average operation duration within surgery type 1 and 2 and the average length of stay at the daycare department for surgery type 2 patients.

| Parameter/ patient category c | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| T c,1 | 32 | 12 | 6 | 11 |
| T c,2 | 15 | 1 | 4 | 22 |
| | | | | |
| O c,1 | 2,4412 | 2,2366 | 1,5532 | 1,3593 |
| O c,2 | 1,4373 | 1,1120 | 1,3974 | 1,0445 |
| | | | | |
| AVG dc,c,2 | 8,8771 | 5,9823 | 7,0278 | 6,3011 |

*Table 3: 2 week patient volume, operation durations and average length of stay at DC per patient category (Sittard)*

Table 4 shows the available resources at the OR, intensive care, nursing unit and daycare unit. The beds at the IC and DC are not allocated per specialism, so the values displayed in Table 4 are based on the total number of IC and DC beds for all specialism. For this reason the target percentage of occupied beds should be changed between 1 and 0 to find the number of IC and DC beds used by the specialism surgery. The length of an operating room block is equal to 4 hours, this means that on Monday (1) 24 hours are available for surgery and can be used by every patient category. The operating room is used for elective patients from Monday (1) till Friday (5), outside this period the operating rooms are only used for emergent patients. The order of the operating room blocks can also be changed when this provides better results; however, as an initial condition the values in Table 4 are chosen. The daycare department is opened from Monday till Friday between 08:00 and 20:00, so 12 hours a day.

| Parameter/ day | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| C orblock,d | 6 | 6 | 4 | 4 | 4 | 0 | 0 |
| C ic, d | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| C nu,d | 43 | 43 | 43 | 43 | 43 | 43 | 43 |
| C dc, d | 50 | 50 | 50 | 50 | 50 | 0 | 0 |

*Table 4: Available resources at OR and wards (Sittard)*

Table 5 shows the arrival rates of emergent patients (first four rows) per day and the arrival rates of patients within surgery type 1 and surgery type 2 without receiving OR also per day of the week. The daycare department is only opened from Monday till Friday, for this reason day 6 and 7 are equal to 0 arrivals. The arrival rates for one week apply to every week in the 2 week planning cycle. The probability $q_d$ that an emergent patient of category c arrives during the planned day schedule is set to 0,45 for all patient categories and all days. In Sittard every day 1,5 hours are allowed to be reserved for the urgent patient flow.

| Parameter/ day | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| β1,d | 0,3077 | 0,2885 | 0,2642 | 0,4423 | 0,3462 | 0,1923 | 0,4231 |
| β2,d | 0,0769 | 0,0769 | 0,0755 | 0,0577 | 0,1346 | 0,0192 | 0,0769 |
| β3,d | 0,0769 | 0,1923 | 0,0755 | 0,1346 | 0,2308 | 0,2308 | 0,1538 |
| β4,d | 0,4038 | 0,3654 | 0,3396 | 0,2500 | 0,3654 | 0,3654 | 0,2308 |
| | | | | | | | |
| h -OR, 1,d | 3,9615 | 2,8077 | 3,6792 | 3,3846 | 2,7500 | 1,9038 | 2,0769 |
| h -OR, 2,d | 3,9615 | 1,8654 | 1,8302 | 1,5769 | 5,9808 | 0 | 0 |

*Table 5: Arrival rates of; emergent patients, patients with s=1 without OR, patients with s=2 without OR (Sittard)*

The average length of stay of a patient with surgery type 2 without receiving OR at the daycare department is equal to 3,2366. For the calculation of the length of stay at the IC and NU for patients with and without receiving a surgical operation, a stochastic length of stay is used. Table 6 shows the length of stay distribution at the IC, and NU for patients with and without receiving a surgical operation. The length of stay distribution is calculated per patient category and per day.

As can be seen in Table 6 any patient within patient category 1 with surgery type 1 has 8,39% chance to be at the IC zero days after surgical operation, since day 0 is the day of the surgical operation ($P_{IC,1,1,0}$). Furthermore, any patient of category 3 with surgery type 1 has 14,83% chance to be at the nursing unit for a period of 8 days after surgery ($P_{NU,3,1,8}$). Some patients are not receiving a surgical operation but are only hospitalized at the nursing unit. For such a patient the chance that this patient is at the nursing for a period of 16 days after hospitalization equals 1,58% ($P_{NU,\cancel{OR},1,16}$).

The length of stay distribution is used to calculate the expected number of occupied beds at the IC and NU. According to Table 6 the maximum length of stay at the IC is equal to 11 days ($L^{max}_{IC(c,1)}$), the maximum length of stay at the NU is equal to 26 days ($L^{max}_{NU(c,1)}$) and the maximum length of stay at the NU for patients without receiving a surgical operation is equal to 19 days ($L^{max}_{NU(1)\ \cancel{OR}}$).

Patients are sometimes not hospitalized at the surgery department because all beds are occupied for some reasons. In this case the patient is hospitalized at another department with bed surplus. Such a patient is called a wrong hospitalization ($H_z$). In order to calculate the number of wrong hospitalizations within the planning horizon of two weeks, the hospitalizations data of 2014 is used. Based on this data set, there were on average 30 wrong hospitalizations within a period of two weeks. This means that the value of $H_z$ in the initial situation is equal to 2 wrong hospitalizations per day.

| Parameter/ day | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P ic,1,1,j | 0,0839 | 0,0465 | 0,0295 | 0,0261 | 0,0238 | 0,0215 | 0,0193 | 0,0181 | 0,0170 | 0,0170 | 0,0136 | 0,0113 | 0 | |
| P ic,2,1,j | 0,6635 | 0,3206 | 0,0254 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| P ic,3,1,j | 0,0191 | 0,0048 | 0,0048 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| P ic,4,1,j | 0,0490 | 0,0232 | 0,0180 | 0,0155 | 0,0129 | 0,0077 | 0,0052 | 0,0052 | 0,0026 | 0,0026 | 0 | 0 | 0 | |
| | | | | | | | | | | | | | | |
| P nu,1,1,j | 0,9161 | 0,8537 | 0,6111 | 0,5249 | 0,4422 | 0,3435 | 0,2687 | 0,2075 | 0,1553 | 0,1327 | 0,1134 | 0,0998 | 0,0941 | 0,0782 |
| P nu,2,1,j | 0,3365 | 0,6032 | 0,7810 | 0,6984 | 0,5873 | 0,5111 | 0,4095 | 0,3111 | 0,2762 | 0,2508 | 0,2286 | 0,2159 | 0,2032 | 0,1937 |
| P nu,3,1,j | 0,9809 | 0,6172 | 0,5215 | 0,4450 | 0,3732 | 0,3206 | 0,2584 | 0,1962 | 0,1483 | 0,1196 | 0,0909 | 0,0813 | 0,0718 | 0,0526 |
| P nu,4,1,j | 0,9510 | 0,6237 | 0,4072 | 0,3222 | 0,2526 | 0,1933 | 0,1289 | 0,0979 | 0,0851 | 0,0722 | 0,0619 | 0,0438 | 0 | 0 |
| | | | | | | | | | | | | | | |
| P nu -OR, 1,j | 1 | 0,7148 | 0,4977 | 0,4110 | 0,3243 | 0,2805 | 0,2321 | 0,1938 | 0,1640 | 0,1407 | 0,1118 | 0,0941 | 0,0783 | 0,0690 |

| Parameter/ day | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P ic,1,1,j | | | | | | | | | | | | | | |
| P ic,2,1,j | | | | | | | | | | | | | | |
| P ic,3,1,j | | | | | | | | | | | | | | |
| P ic,4,1,j | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| P nu,1,1,j | 0,0669 | 0,0544 | 0,0317 | 0,0215 | 0,0125 | 0,0079 | 0,0057 | 0,0023 | 0 | 0 | 0 | 0 | 0 | 0 |
| P nu,2,1,j | 0,1683 | 0,1587 | 0,1365 | 0,1302 | 0,1143 | 0,1048 | 0,0952 | 0,0889 | 0,0794 | 0,0730 | 0,0667 | 0,0667 | 0,0127 | 0 |
| P nu,3,1,j | 0,0335 | 0,0335 | 0,0239 | 0,0048 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P nu,4,1,j | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | | | | | | | | | | | | |
| P nu -OR, 1,j | 0,0606 | 0,0494 | 0,0158 | 0,0093 | 0,0075 | 0,0047 | 0 | | | | | | | |

*Table 6: Length of stay distribution IC, NU and NU without OR (Sittard)*

##### *5.3.2.2 Unique model characteristics of Heerlen*

Table 7 shows the target number of elective patients within surgery type 1 and 2 and within the four patient groups to be operated during the planning horizon of 2 weeks. Also the average operation durations within surgery type 1 and 2 and within the four patient categories are displayed in Table 7. The last values displayed in Table 7 are the average length of stay at the daycare department for surgery type 2 within the four patient categories.

| Parameter/ patient category c | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| T c,1 | 57 | 17 | 8 | 13 |
| T c,2 | 15 | 2 | 9 | 38 |
| | | | | |
| O c,1 | 2,2255 | 2,3533 | 1,8735 | 1,2928 |
| O c,2 | 1,2954 | 1,1698 | 1,3311 | 0,8917 |
| | | | | |
| AVG dc,c,2 | 8,2727 | 8,4083 | 7,9475 | 7,3872 |

*Table 7: 2 week patient volume, operation durations and average length of stay at DC per patient category (Heerlen)*

Table 8 shows the available resources at the OR, intensive care, nursing unit and daycare unit. The beds at the IC and DC are not allocated per specialism, so the values displayed in Table 8 are based on the total number of IC and DC beds for all specialism. This is the reason why the target percentage of occupied beds is implemented into the mathematical model. In this way, it becomes possible to change the target percentage between 1 and 0 to find the number of IC and DC beds used by the specialism surgery. The length of an operating room block is equal to 4,5 hours, this means that on Monday (1) 40,5 hours are available for surgery and can be used by every patient category. The operating room is used for elective patients from Monday (1) till Friday (5), outside this period the operating rooms are only used for emergent patients. The order of the operating room blocks can also be changed when this provides better results; however, as an initial condition the values in Table 8 are chosen. The daycare department is opened from Monday till Friday between 07:00 and 21:00, so 14 hours a day.

In Heerlen there is one emergent operating room which is only used for emergent patients. This means that the urgent patient flow does not really affect the planned OR schedule. For this reason no OR capacity is reserved in the planned OR schedule for emergent patients. So the parameter $E_1$ is not used in the mathematical model of Heerlen.

| Parameter/ day | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| C orblock,d | 9 | 8 | 8 | 8 | 8 | 0 | 0 |
| C ic, d | 21 | 21 | 21 | 21 | 21 | 21 | 21 |
| C nu,d | 62 | 62 | 62 | 62 | 62 | 62 | 62 |
| C dc, d | 70 | 70 | 70 | 70 | 70 | 0 | 0 |

*Table 8: Available resources at OR and wards (Heerlen)*

The arrival rates of emergent patients (first four rows) per day and the arrival rates of patients within surgery type 1 and surgery type 2 without receiving OR also per day of the week can be found in Table 9. The daycare department is only opened from Monday till Friday, for this reason day 6 and 7 are equal to 0 arrivals. The arrival rates for one week apply to every week in the 2 week planning cycle. The probability $q_d$ that an emergent patient of category c arrives during the planned day schedule is set to 0,46 for all categories and all days. As described above the emergent OR in Heerlen is available during the day for emergent patients. For this reason also the probability $q_d$ is not needed in the mathematical model of Heerlen. However, the probability $q_d$ is later used to show that the time “reserved” for the urgent patient flow through the emergent OR is enough to treat the urgent patient flow as fast as possible.

| Parameter/ day | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| β1,d | 1,1154 | 1,5962 | 1,0377 | 0,9615 | 1,2308 | 0,9231 | 0,6731 |
| β2,d | 0,6154 | 0,8077 | 0,6604 | 0,7692 | 0,5192 | 0,3269 | 0,2115 |
| β3,d | 0,6731 | 0,5577 | 0,6981 | 0,5769 | 1,1346 | 0,9808 | 0,8077 |
| β4,d | 1,8462 | 1,6923 | 1,9245 | 1,8654 | 2,1154 | 1,0000 | 1,2115 |
| | | | | | | | |
| h -OR, 1,d | 9,3077 | 8,4808 | 8,1321 | 7,9231 | 8,5577 | 5,4038 | 5,1154 |
| h -OR, 2,d | 2,2308 | 2,0385 | 2,0943 | 2,5769 | 2,4038 | 0 | 0 |

*Table 9: Arrival rates of; emergent patients, patients with s=1 without OR, patients with s=2 without OR (Heerlen)*

The average length of stay of a patient with surgery type 2 without receiving OR at the daycare department is equal to 3,9521. For the calculation of the length of stay at the IC and NU for patients with and without receiving a surgical operation, a stochastic length of stay is used. The length of stay distribution is calculated per patient category and per day. The values of the length of stay distribution at the IC and NU for patients with and without receiving a surgical operation can be found in Table 10.

Table 10 shows that any patient within patient category 2 with surgery type 1 has 22,56% chance to be at the IC zero days after surgical operation, since day 0 is the day of the surgical operation ($P_{IC,2,1,0}$). Furthermore, any patient of category 4 with surgery type 1 has 10,59% chance to be at the nursing unit for a period of 6 days after surgery ($P_{NU,4,1,6}$). Some patients are not receiving a surgical operation but are only hospitalized at the nursing unit. For such a patient the chance that this patient is at the nursing for a period of 11 days after hospitalization equals 4,67% ($P_{NU,\cancel{OR},1,11}$).

The length of stay distribution is used to calculate the expected number of occupied beds at the IC and NU. According to Table 10 the maximum length of stay at the IC is equal to 15 days ($L_{IC(c,1)}^{max}$), the maximum length of stay at the NU is equal to 20 days ($L_{NU(c,1)}^{max}$) and the maximum length of stay at the NU for patients without receiving a surgical operation is equal to 14 days ($L_{NU(1)\ \cancel{OR}}^{max}$).

It is sometimes not possible to hospitalize all patients within the specialism surgery at the surgery nursing unit. In this case the patient is hospitalized at another department with bed surplus. Such a patient is called a wrong hospitalization ($H_z$). Based on the hospitalizations data of 2014, there were on average 57 wrong hospitalizations within a period of two weeks. This means that the value of $H_z$ in the initial situation is equal to 4 wrong hospitalizations per day.

| Parameter/ day | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| P ic,1,1,j | 0,1246 | 0,1064 | 0,0766 | 0,0608 | 0,0526 | 0,0433 | 0,0409 | 0,0392 | 0,0374 | 0,0368 | 0,0345 |
| P ic,2,1,j | 0,2256 | 0,1842 | 0,1259 | 0,0752 | 0,0677 | 0,0508 | 0,0451 | 0,0376 | 0,0338 | 0,0263 | 0,0244 |
| P ic,3,1,j | 0,0460 | 0,0372 | 0,0306 | 0,0197 | 0,0175 | 0,0131 | 0,0131 | 0,0109 | 0,0109 | 0,0109 | 0,0088 |
| P ic,4,1,j | 0,0473 | 0,0439 | 0,0360 | 0,0282 | 0,0225 | 0,0180 | 0,0180 | 0,0169 | 0,0146 | 0,0124 | 0,0011 |
| | | | | | | | | | | | |
| P nu,1,1,j | 0,8754 | 0,7497 | 0,4778 | 0,3901 | 0,3152 | 0,2620 | 0,1982 | 0,1532 | 0,1292 | 0,1018 | 0,0848 |
| P nu,2,1,j | 0,7744 | 0,7726 | 0,6353 | 0,5827 | 0,4436 | 0,3421 | 0,2556 | 0,1992 | 0,1447 | 0,1297 | 0,1147 |
| P nu,3,1,j | 0,9540 | 0,7571 | 0,5886 | 0,4923 | 0,3654 | 0,2298 | 0,1751 | 0,1357 | 0,1138 | 0,1007 | 0,0678 |
| P nu,4,1,j | 0,9527 | 0,5755 | 0,3322 | 0,2658 | 0,2083 | 0,1610 | 0,1059 | 0,0743 | 0,0495 | 0,0383 | 0,0417 |
| | | | | | | | | | | | |
| P nu -OR, 1,j | 1,0000 | 0,7736 | 0,4471 | 0,3507 | 0,2783 | 0,2217 | 0,1659 | 0,1246 | 0,0935 | 0,0728 | 0,0562 |

| Parameter/ day | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| P ic,1,1,j | 0,0327 | 0,0322 | 0,0304 | 0,0287 | 0,0281 | 0 | | | | | |
| P ic,2,1,j | 0 | 0 | 0 | 0 | 0 | 0 | | | | | |
| P ic,3,1,j | 0,0088 | 0,0088 | 0,0066 | 0,0066 | 0 | 0 | | | | | |
| P ic,4,1,j | 0 | 0 | 0 | 0 | 0 | 0 | | | | | |
| | | | | | | | | | | | |
| P nu,1,1,j | 0,0713 | 0,0596 | 0,0480 | 0,0404 | 0,0327 | 0,0123 | 0,0070 | 0,0018 | 0 | 0 | 0 |
| P nu,2,1,j | 0,1353 | 0,1259 | 0,1109 | 0,0921 | 0,0883 | 0,0883 | 0,0714 | 0,0658 | 0,0056 | 0,0038 | 0 |
| P nu,3,1,j | 0,0635 | 0,0591 | 0,0481 | 0,0066 | 0,0044 | 0 | 0 | 0 | 0 | 0 | 0 |
| P nu,4,1,j | 0,0056 | 0 | | | | | | | | | |
| | | | | | | | | | | | |
| P nu -OR, 1,j | 0,0467 | 0,0170 | 0,0094 | 0,0043 | 0 | | | | | | |

*Table 10: Length of stay distribution IC, NU and NU without OR (Heerlen)*

### *5.3.3 Mathematical model testing*

Our mathematical model should be tested with the use of the values of the input parameters displayed in section 5.3.2 for Sittard and Heerlen separately. Since those values are related to the current situation in both hospitals, it can be expected that the number of wrong hospitalizations is not equal to zero, that the bed occupancy is high and that the bed surplus is low. The OR occupancy should also be high, because otherwise there would be no bed deficit and no wrong hospitalizations. The bed occupancy at the IC and DC are expected to be very low, since all available capacity for all specialism is used to test our mathematical model.

The results of the model testing can be found in Table 11. The values of the input parameters related to the current situation do not show an integer solution for both Sittard and Heerlen. All elective patients who need to be scheduled for OR are planned. The OR occupancy was expected to be high, this is the case for Sittard; however the OR occupancy for Heerlen could be higher. The number of wrong hospitalizations is equal to zero for Sittard, also the bed occupancy at the NU is moderate. So the reason why no integer solution exists for the current situation of Sittard cannot be found in the bed occupancy at the NU. The number of wrong hospitalizations in Heerlen is equal to 120, this is a very high number which could be related to the bed occupancy at the NU which is equal to 1,0573. The reason why no integer solution exists for the current situation in Heerlen can found in the bed occupancy at the NU which is higher than 1. The bed occupancy rates at the IC and DC for both locations are very low, which satisfies the expectations. The model testing results in more detail can be found in Appendix C. Model results Sittard, Table 36 and in Appendix D. Model results Heerlen, Table 42.

| **Model testing** | **Sittard** | **Heerlen** |
|---|---|---|
| All elective patients planned for OR | YES | YES |
| Integer solution | NO | NO |
| OR occupancy | 0,9816 | 0,7189 |
| Bed occupancy IC | 0,1642 | 0,3210 |
| Bed occupancy NU | 0,8567 | 1,0573 |
| Bed occupancy DC | 0,0674 | 0,0595 |
| Number of wrong hospitalizations | 0 | 120 |
| Value objective function | 20130 | 34482 |

*Table 11: Model testing results Sittard and Heerlen*

After some experimentations with the values of b1 and b2, it can be concluded that those values are only important when the maximum capacity at the IC, NU and DC are very tight. When in this case the value of b1 is set to 0 and the value of b2 is set to -100, the mathematical model chooses to have a very high number of wrong hospitalizations, and less surplus. This shows that the construction of the values b1 and b2 works well.

According to Table 11, the values of the input parameters are not sufficient for the current situation. Chapter 6 provides more detail about the case study and provides a scenario analysis which shows ways to change the values of the input parameters in order to make the results more sufficient. When it is not possible to create an integer and sufficient solution, the possibility exists that the mathematical model does contain mistakes.

# 6. Case study

The model testing phase in section 5.3.3 shows that the values of the input parameters are not sufficient for the creation of a solution with integer values. This chapter provides a scenario analysis based on changing some of the values of the input parameters. This should lead to a sufficient and integer solution. Section 6.1 describes the scenario analysis of Sittard and section 6.2 describes the scenario analysis of Heerlen. Section 6.3 provides a short summary based on the scenario analyses.

Scenarios which can be tested are:

- Changing the maximum bed capacity at the nursing unit
- Changing the allowed number of wrong hospitalizations without creating bed deficit
- Changing the order of OR blocks per day
- Changing the maximum OR capacity
- Changing the target percentage of occupied beds at the IC and DC
- Changing the reserved OR capacity for emergent patients

Not every scenario is tested for Sittard and Heerlen, only those scenarios which will lead to a better solution than provided in the model testing phase. It is important to realize that it is not possible to change all the scenarios at the same moment. The consequences of changing on of the scenarios will not be visible anymore when every scenario is changed at the same moment. It is also important to create an integer solution first.

The occupancy rates displayed in Table 12 and Table 13 are based on averages, in Appendix C. Model results Sittard and in Appendix D. Model results Heerlen more detailed tables and analyses can be found.

## 6.1 Scenario analysis Sittard

Table 12 shows the results of the scenario analysis for the situation in Sittard. In order to see the differences with regard to the testing phase also those results are displayed in Table 12. The OR occupancy and the bed occupancy at the nursing unit in the testing phase are not low; however, still no integer solution exists. Since the operating room is the unit before the nursing unit, the bottleneck should first be searched at the operating room capacity.

### *6.1.1 Scenario 1: Changing the reserved OR capacity for emergent patients*

The results of scenario 1 can be found in Table 12, a more detailed table with results and a more detailed analysis of this scenario can be found in Appendix C. Model results Sittard, Table 37. The time needed for the urgent patient flow arriving during the day is equal to 7,5734 hours in two weeks. The time reserved for the urgent patient flow equals 15 hours in two weeks. The OR capacity needed to treat all elective patients during two weeks equals 180,4692 hours. Every week 24 OR blocks are available to treat all elective and emergent patients. This means that the available OR capacity in two weeks equals 192 hours. When 15 hours in two weeks need to be reserved for the urgent patient flow, only 177 hours in two weeks remain for the elective patient flow which is not enough. So this could be the reason why no integer solution existed in the model testing phase.

The reserved OR capacity for the urgent patient flow is therefore changed to one hour per day, the maximum bed capacity at the nursing unit is still equal to 43, the allowed number of wrong hospitalizations is equal to 2 and the order of the OR blocks is equal to 6,6,4,4,4 (Monday - Friday). It can be expected that the solution does contain integer values, since the OR capacity division should be enough to treat all patients.

As can be seen in Table 12, scenario 1 shows an integer solution. The OR occupancy is still almost 100% and the bed capacity at the nursing unit is still high. The bed occupancy at the IC and DC are very low because the target percentage of occupied beds at the IC and DC is still equal to 1. Scenario 1 shows 3 wrong hospitalizations.

#### *6.1.2 Scenario 2: Changing the order of OR blocks per day*

The order of the OR blocks should be determined by the bed occupancy at the nursing unit per day, because at days with a high bed occupancy, less patients should be scheduled for surgical operation than on days with a low bed occupancy.

As can be seen in Table 37 the bed occupancy at the nursing unit is equal to 0,7753 and 0,8938 on Monday and the bed occupancy at the nursing unit is equal to 0,9889 and 0,9745 on Tuesday. The other days are more or less the same. This means that on Monday more OR blocks should be scheduled than on Tuesday and the other days of the week.

The maximum number of available beds at the nursing unit is still equal to 43, the allowed number of wrong hospitalizations equals 2 and the order of the OR blocks is changed to 8,3,5,4,4. It can be expected that the number of wrong hospitalizations is decreased with regard to the number of wrong hospitalizations in scenario 1.

The results of scenario 2 can be found in Table 12 and a more detailed table with results of scenario 2 can be found in Appendix C. Model results Sittard Table 38. The number of wrong hospitalizations is decreased by 1 with regard to scenario 1.

#### *6.1.3 Scenario 3: Changing the allowed number of wrong hospitalizations without creating bed deficit*

As can be seen in Table 12 the bed occupancy at the nursing unit in scenario 2 is equal to 0,8596. The occupancy rate is determined by allowing 2 wrong hospitalizations per day, since this number was calculated from the hospitalizations data of Sittard. In order to prove that the maximum available bed capacity at the nursing unit of surgery is enough to hospitalize all patients within the specialism surgery, the allowed number of wrong hospitalizations should be set to zero.

So the maximum bed capacity at the nursing unit is equal to 43 and the OR schedule is still equal to 8,3,5,4,4. It can be expected that the number of wrong hospitalizations becomes equal to zero without creating bed deficit at the nursing unit. Table 12 shows the results of scenario 3, a more detailed table with results can be found in Appendix C. Model results Sittard, Table 39. According to Table 12, the number of wrong hospitalizations is equal to zero in scenario 3 and the bed occupancy at the nursing unit is now equal to 0,9003.

#### *6.1.4 Scenario 4: Changing the maximum bed capacity at the nursing unit*

The bed occupancy in scenario 3 is equal to 0,9003 which is high; however, there is still space left. Scenario 4 shows the consequences of changing the maximum bed capacity at the nursing unit.

The maximum bed capacity at the nursing unit is set to 41 beds, the allowed number of wrong hospitalizations is still equal to 0 and the order of the OR blocks is equal to 8,3,5,4,4. It can be expected that the number of wrong hospitalizations remains zero and that the bed occupancy at the nursing unit will increase.

The results of scenario 4 can be found in Table 12, a more detailed table with results can be found in Appendix C. Model results Sittard Table 40. According to Table 12 the number of wrong hospitalizations is equal to 0 and the bed occupancy at the nursing unit is equal to 0,9444. Table 40 in Appendix C. Model results Sittard shows that the bed occupancy at the nursing unit is higher than 90% at 11 days of the 14 days in the planning cycle. This means that the maximum number of available beds at the nursing unit should not be decreased further.

### *6.1.5 Scenario 5: Changing the target percentage of occupied beds at the IC and DC*

Scenario 1 to 4 show very low bed occupancy rates at the IC and DC. The input parameter displaying the target percentage of occupied beds at the IC and DC can be used in the determination of the number of IC beds and DC beds used by one specific specialism.

As can be seen in Table 12, the bed occupancy at the IC in scenario 1 to 4 is equal to 0,1642. This means that (0,1642*12) ≈ 2 IC beds are used by the specialism surgery. In order to make the IC bed capacity not too tight, the number of required IC beds is expected to be equal to 3, which means that the target percentage of occupied beds at the IC is set to (3/12) = 0,25.

The bed occupancy at the DC is equal to 0,0674 according to scenario 1 to 4 in Table 12. This means that (0,0674*50) ≈ 4 DC beds are used by the specialism surgery. In order to make the DC bed capacity not too tight, the number of required DC beds is expected to be equal to 5. This means that the target percentage of occupied DC beds is set to (5/50) = 0,10.

It can be expected that the bed occupancy at the IC and DC becomes higher and the rest of the results remains the same with regard to earlier scenarios. The results of scenario 5 can be found in Table 12, a more detailed table with the results of scenario 5 can be found in Appendix C. Model results Sittard, Table 41. According to Table 12, the bed occupancy at the IC is equal to 0,6568 and the bed occupancy at the DC is equal to 0,6739. It is not possible to decrease the target percentage of occupied beds at the IC and DC even more, because then the solution does not contain integer values anymore. So scenario 5 can be seen as a good solution for Sittard.

| Scenario analysis (Sittard) | Testing phase | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 | Scenario 5 |
|---|---|---|---|---|---|---|
| All elective patients planned for OR | YES | YES | YES | YES | YES | YES |
| Integer solution | NO | YES | YES | YES | YES | YES |
| OR occupancy | 0,9816 | 0,9795 | 0,9783 | 0,9772 | 0,9780 | 0,9771 |
| Bed occupancy IC | 0,1642 | 0,1642 | 0,1642 | 0,1642 | 0,1642 | 0,6568 |
| Bed occupancy NU | 0,8567 | 0,8604 | 0,8596 | 0,9003 | 0,9444 | 0,9408 |
| Bed occupancy DC | 0,0674 | 0,0674 | 0,0674 | 0,0674 | 0,0674 | 0,6739 |
| Number of wrong hospitalizations | 0 | 3 | 2 | 0 | 0 | 0 |
| Value objective function | 20130 | 20340 | 20150 | 20100 | 19110 | 1830 |

*Table 12: Results scenario analysis Sittard*

## 6.2 Scenario analysis Heerlen

Table 13 shows the results of the scenario analysis for the situation in Heerlen. In order to see the differences with regard to the testing phase also those results are displayed in Table 13. In the testing phase no integer solution could be found. A reason for this can be that the bed occupancy rate at the nursing is higher than 1. This means that there were not enough beds available to hospitalize all patients.

### *6.2.1 Scenario 1: Changing the maximum bed capacity at the nursing unit*

It is important to first create an integer solution. The testing phase shows an bed occupancy at the nursing unit of 1,0573 and a number of wrong hospitalizations equal to 120, which means that there are not enough beds available to hospitalize all patients. In order to be sure about the feasibility of the mathematical model, the maximum available bed capacity at the nursing unit is changed to a very high number. According to Table 42 in Appendix D. Model results Heerlen, the highest expected number of beds at the nursing unit is equal to 74,6866. So the maximum available bed capacity at the nursing unit is set to 80 beds, because making the maximum bed capacity too tight in the first place would not create an integer solution.

So with a maximum available bed capacity at the nursing unit of 80 beds and the number of wrong hospitalizations set to zero, it can be expected that our mathematical model shows a solution; with integer values, with no bed deficit and with no wrong hospitalizations.

As can be seen in Table 13 the results of scenario 1 show that the bed occupancy at the nursing unit is equal to 0,8727 and that the number of wrong hospitalizations is equal to zero. The results of scenario 1 show an integer solution which provides proof for the feasibility of our mathematical model. A more detailed table with results of scenario 1 can be found in Appendix D. Model results Heerlen, Table 43.

### *6.2.2 Scenario 2: Changing the order of OR blocks per day*

As can be seen in Table 43 in Appendix D. Model results Heerlen, the bed occupancy at the nursing unit on Monday is equal to 0,8335 and 0,8715 and on Friday is equal to 0,8995 and 0,8559. At the other days of the week, the bed occupancy rates are above 0,9 so the order of the OR blocks should be determined by the lower occupancy rates at the nursing unit. This seems logical, because at days with high occupancy rates, less patients should be scheduled for surgical operations than on days with low occupancy rates.

So the available 41 OR blocks are now used in a different order with different quantities. The order of the OR blocks becomes 10,7,7,7,10 (Monday till Friday). The maximum number of available beds at the nursing unit is still equal to 80 and the allowed number of wrong hospitalizations is equal to zero. It can be expected that the bed occupancy rates at the nursing unit on Monday and Friday are increasing, and that the variation in the bed occupancy rates at the nursing unit becomes less.

Table 13 shows the results of scenario 2, a more detailed table with results of scenario 2 can be found in Appendix D. Model results Heerlen, Table 44. According to Table 13 the bed occupancy rate at the nursing unit is not changed; however, according to Table 44 in Appendix D. Model results Heerlen there is more dispersion within the bed occupancy rates over the days of the week.

### *6.2.3 Scenario 3: Changing the maximum OR capacity*

Table 13 shows an OR occupancy of 0,7187 in scenario 2. It is therefore important to check the relation between the maximum OR capacity and the OR capacity needed to treat all elective patients.

The urgent patient flow is scheduled at the emergent operating room, available during the day. The time needed for the urgent patient flow arriving during the day is equal to 36,9724 over two weeks. This number is less than 90 hours which are the available OR hours in two weeks for the urgent patient flow during the day. So the urgent patient flow can be treated at the emergent operating room.

The maximum OR capacity needed to treat all elective patients is equal to 266,2891 hours in two weeks. The maximum available OR capacity is equal to 369 hours in two weeks. This means that the available OR capacity contains about 100 hours more than needed.

The maximum available OR capacity is decreased to 30 OR blocks per week. The maximum bed capacity at the nursing unit is still equal to 80 beds and the order of the OR blocks is set to 8,5,5,5,7 because on Monday and Friday the bed occupancy rates are less than on other days of the week (Table 44 in Appendix D. Model results Heerlen). It can be expected that the OR occupancy rate increases and that the bed occupancy rate at the nursing unit remains more or less the same as in the other scenarios.

Table 13 shows the results of scenario 3, a more detailed analysis and table with the results of scenario 3 can be found in Appendix D. Model results Heerlen, Table 45. According to Table 13 the OR occupancy is now equal to 0,9860, which is higher than the OR occupancy rates shown in scenario 1 and 2. The bed occupancy at the nursing unit is not changed much according to earlier scenarios.

### 6.2.4 Scenario 4: Changing the maximum bed capacity at the nursing unit (2)

In scenario 1, the maximum available bed capacity is set to 80 beds; however, by changing some other values of the input parameters in other scenarios, the bed occupancy at the nursing unit is now equal to 0,8726 in scenario 3 (Table 13). This means that the maximum available bed capacity at the nursing unit can be decreased to 74 beds, this number is chosen since the average required number of beds equals (0,8726*80) ≈ 70 beds. However, this is on average and Table 45 in Appendix D. Model results Heerlen also shows bed occupancy rates of above 0,99. Therefore a maximum available bed capacity of 74 beds seems logical.

It can be expected that the bed occupancy rate at the nursing unit increases and that the number of wrong hospitalizations remains zero. The results of scenario 4 can be found in Table 13, a more detailed table with results of scenario 4 can be found in Appendix D. Model results Heerlen, Table 46. As can be seen in Table 13 the bed occupancy at the nursing unit is equal to 0,9426 and the number of wrong hospitalizations is still equal to zero.

### 6.2.5 Scenario 5: changing the target percentage of occupied beds at the IC and DC

The input parameter displaying the target percentage of occupied beds at the IC and DC can be used in the determination of the number of IC beds and DC beds used by one specific specialism.

The bed occupancy at the IC is equal to 0,3210 during the first 4 scenarios (Table 13). This means that (0,3210*21) ≈ 7 IC beds are used by the specialism surgery. In order to make the IC bed capacity not too tight, the number of required IC beds is expected to be equal to 8, which means that the target percentage of occupied beds at the IC is set to (8/21) = 0,38.

The bed occupancy at the DC is equal to 0,0595 during scenario 1 to 4 (Table 13). This means that (0,0595*70) ≈ 5 DC beds are used by the specialism surgery. In order to make the DC bed capacity not too tight, the number of required DC beds is expected to be equal to 7. This means that the target percentage of occupied DC beds is set to (7/70) = 0,10.

It can be expected that the bed occupancy at the IC and DC increases, that the OR occupancy and the bed occupancy at the nursing unit do not change much and that the number of wrong hospitalizations is still equal to zero. Table 13 shows the results of scenario 5, a more detailed table with the results of scenario 5 can be found in Appendix D. Model results Heerlen, Table 47. Following Table 13, the bed occupancy at the IC is equal to 0,8448 and the bed occupancy at the DC is equal to 0,5947. The OR occupancy and the bed occupancy at the nursing unit are not changed, also the number of wrong hospitalizations is still zero. Decreasing the target percentage of occupied beds at the IC and DC even more, does not provide an integer solution and creates bed deficit. So scenario 5 can be seen as a good result for the situation in Heerlen.

| Scenario analysis (Heerlen) | Testing phase | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 | Scenario 5 |
|---|---|---|---|---|---|---|
| All elective patients planned for OR | YES | YES | YES | YES | YES | YES |
| Integer solution | NO | YES | YES | YES | YES | YES |
| OR occupancy | 0,7189 | 0,7150 | 0,7187 | 0,9860 | 0,9852 | 0,9860 |
| Bed occupancy IC | 0,3210 | 0,3210 | 0,3210 | 0,3210 | 0,3210 | 0,8448 |
| Bed occupancy NU | 1,0573 | 0,8727 | 0,8727 | 0,8726 | 0,9426 | 0,9426 |
| Bed occupancy DC | 0,0595 | 0,0595 | 0,0595 | 0,0595 | 0,0595 | 0,5947 |
| Number of wrong hospitalizations | 120 | 0 | 0 | 0 | 0 | 0 |
| Value objective function | 34482 | 29850 | 29970 | 29940 | 27480 | 3150 |

*Table 13: Results scenario analysis Heerlen*

## 6.3 Summary

The scenario analyses of Sittard and Heerlen show that minor changes in the values of the input parameters can have large consequences for the values of the OR occupancy, bed occupancy at the NU, IC and DC and also on the number of wrong hospitalizations. The fact that no integer solution existed in the first place, does not have to mean that the developed mathematical model contains mistakes or does not work well. It is also possible that the provided data sets are incomplete. The scenario analyses show that a sufficient integer solution for the admission planning related to the bed capacity constraints is possible for Sittard and Heerlen.

# 7. Implementation

Our mathematical model can be implemented easily since the model is built in MS Excel using the Excel solver. For an optimal use of the mathematical model, the open solver should be downloaded from the internet because otherwise solving the model takes too much time.

The parameters which can be changed in the mathematical model are colored blue in order to create a user friendly interface and quick use. The solver solution is colored green to show the difference between the input parameters and the solution.

Our mathematical model can be used to determine the OR capacity and the related bed capacity needed when patient flows are crossing locations in the future. When the merger process continues, some of the patient categories within surgery will be allocated for the surgical operation to Sittard or to Heerlen. When the target number of elective patients increases the consequence for the OR capacity and bed capacity can be easily calculated with the use of our mathematical model.

The case study in chapter 6 is focused on the specialism surgery only; however, our mathematical model can also be used for other specialism or all specialism in the hospital together. When the model built in MS Excel is used for other specialism than surgery, it is important to realize that the data should be collected and analyzed again and that also the way of treating patients without receiving a surgical operation should be considered. Our mathematical model is based on general principles and can therefore be used in many different situations. However, every specialism is different, so it is possible that minor changes are needed to make the mathematical model applicable to a specific specialism which is done in this report for the specialism surgery.

As can be seen in chapter 6 different scenarios could be used in the determination of the bed deficit, bed surplus and the number of wrong hospitalizations. Changing the values of the input parameters concerned with those scenarios provide tactical information about the OR capacity related to the bed capacity. The scenarios which can be used are:

- Changing the target number of elective patients to be operated during the planning horizon
- Changing the maximum bed capacity at the nursing unit
- Changing the allowed number of wrong hospitalizations without creating bed deficit
- Changing the order of OR blocks per day
- Changing the maximum OR capacity
- Changing the reserved OR capacity for the urgent patient flow
- Changing the target percentage of occupied beds at the IC and DC
- Changing the values of constant b1 and b2

When something in one of the scenarios changes for the situation of Sittard and Heerlen, our mathematical model should be run again. Our mathematical model can also be run again when the hospital wants to know what happens when something in one of the scenarios changes in the future. The model built in MS Excel solver can be run by changing the values of one of the input parameters and then click on solve, when no feasible and integer solution is possible a message is shown on the screen containing this information. When a feasible and integer solution is possible, this solution with the associated bed deficit, bed surplus and number of wrong hospitalizations is shown. It is important to change one input parameter value at the same time, because otherwise when no feasible and integer solution exists, it is not easy to find the input parameter value which causes this solution.

Our mathematical model therefore tries to create some awareness of the fact that increasing the OR capacity or changing the admission planning has directly consequences for the bed capacity.

# 8. Conclusions and recommendations

This chapter presents the conclusions which can be drawn from this research. In section 8.1 the main findings are displayed. Section 8.2 is focused on the recommendations to the Zuyderland MC. In section 8.3 the limitations of this report and the suggestions for further research are displayed.

## 8.1 Main findings

Clinical pathways for the specialism surgery were created for both locations (Sittard and Heerlen) of the Zuyderland MC. Those clinical pathways should provide insight in the current way of working and planning patients for a surgical operation. The differences in the clinical pathways for surgery at both locations show that the OR planning is not related to the bed capacity. It is therefore possible that surgical operations are cancelled or patients are hospitalized at different nursing units than the nursing unit of the operating specialism.

The number of wrong hospitalizations over the year 2014 was equal to two patients per day in Sittard and four patients per day in Heerlen. This means that every day bed deficit was created because otherwise patients should not have been hospitalized at a different nursing unit. It is therefore important to take into account the number of wrong hospitalizations. A method is developed for tactical planning taking into account the number of wrong hospitalizations by considering both the surgical operations as well as the required nursing. Articles found in literature mainly focus on the relation between the OR planning and some bed capacity constraints. However, in this thesis not only the patients who received a surgical operation are taken into account, also the patients who did not receive a surgical operation. The choice was therefore made to develop a tactical plan which relates the admission planning to the bed capacity. This tactical plan is based on the development of a mathematical model (MILP) which relates the admission planning to the bed capacity by minimizing the bed deficit, bed surplus and the number of wrong hospitalizations.

It is important to not only focus on the clinical patients but also on the daycare patients, since many surgical operations are nowadays performed by daycare surgery instead of clinical surgery. Another important aspect is the fact that both clinical surgeries and daycare surgeries are performed in the same operating rooms. This means that the OR occupancy is depended on both clinical surgeries and daycare surgeries.

The urgent patient flow is also taken into account, since emergent patients arriving during the day could affect the planned OR schedule. It is therefore important to reserve some OR capacity per day for the urgent patient flow. In this way, it becomes less common that patients should be cancelled because of an emergent patient.

As described earlier our mathematical model takes into account patients with and without receiving a surgical operation. This choice was made because patients who did not receive a surgical operation were hospitalized at the nursing unit or at the daycare unit and were in fact occupying a clinical bed or daycare bed. When those patients are not counted in the calculation of the bed occupancy at the nursing unit and daycare unit, it is not possible to create a realistic representation of reality. When our mathematical model is then used in practice, it might not be possible to draw realistic conclusions and create a tactical plan based on the results of the mathematical model.

Our mathematical model is translated to a MS Excel Solver tool which can be used by the hospital in creation of tactical plans based on the relation between the admission planning and bed capacity. The mathematical model is tested with the use of the data sets of the year 2014 from Sittard and Heerlen. After running the MS Excel Solver tool with the analyzed data from 2014, no integer solution existed for both locations. Therefore a scenario analysis was executed for both locations to show that an integer solution with no bed deficit and no wrong hospitalizations existed.

The results of the scenario analysis of Sittard showed that in the first place, no integer solution existed because the reserved OR capacity for the urgent patient flow was too large which meant that there was not enough OR capacity left to treat the elective patient flow. After changing the reserved OR capacity for the urgent patient flow, an integer solution existed. The scenario analysis showed that the maximum available bed capacity at the nursing unit could be decreased by two beds, so 41 beds instead of 43 beds without creating bed deficit or wrong hospitalizations. So it can be concluded that it is not needed to have wrong hospitalizations since the current available bed capacity at the nursing unit of surgery is enough to hospitalize all patients with and without receiving a surgical operation.

The scenario analysis results of Heerlen show that no integer solution existed because the bed occupancy at the nursing unit was higher than 1. This meant that many wrong hospitalizations and a large bed deficit existed. After increasing the maximum available bed capacity at the nursing unit, an integer solution appeared. Another remarkable thing discovered during the scenario analysis was that the available OR hours in 2 weeks contained 100 hours more than needed to treat all elective patients. The urgent patient flow is treated in the emergent operating room in Heerlen which means that those patients did not affect the planned OR schedule. So it can be concluded that an increased bed capacity at the nursing unit and an OR capacity of less than 100 hours creates an integer solution without bed deficit and wrong hospitalizations.

The fact that no integer solution existed for both locations in the first place, can be explained by the separate planning of the operating rooms and the bed capacity at the wards. When problems existed in reality, last moment arrangements are used to control the situation. This is the reason why wrong hospitalizations are created. When the reserved OR capacity for the urgent patient flow in Sittard is not used, the care planning can choose to schedule the remaining OR capacity for elective patients. Those considerations are based on manual actions which cannot be translated into a mathematical model. The scenario analyses of both locations show that the mathematical model does not contain mistakes since changing the values of the input parameters provided an integer solution. In the case of Heerlen, the results of the scenario analysis were very different from the values of the input parameters of the current situation, so it could be possible that the data set of Heerlen was incomplete. However, the number of elective patients to be treated at the OR in two weeks is checked twice, so in that case the conclusion about the OR capacity could be useful. The last important aspect related to the OR schedule for both locations is that the available OR capacity is allocated per patient category. In this way, manual actions are needed to control the situation when some OR blocks cannot be planned entirely. Our mathematical model uses a flexible OR schedule which means that every patient is planned in the OR schedule at a day which is “optimal” for the OR and for the wards. This could also be a reason why our mathematical model shows no bed deficit and no wrong hospitalizations at the nursing unit for Sittard and Heerlen.

The most important conclusion is that hospitals should understand the principles of chain logistics which mean in this case that both units, OR and wards, are connected to each other and are not operating on its own. So creating a bottleneck at one unit directly implies the creation of a bottleneck at the other unit. It is therefore important to always relate the admission planning to the bed capacity constraints.

## 8.2 Recommendations

The recommendations are divided into two categories, recommendations with regard to the tactical planning and other recommendations.

### *8.2.1 Recommendations with regard to the tactical planning*

Our mathematical model should be used to determine:

- The required number of IC, NU and DC beds
- The required number of OR blocks per week
- The OR capacity needed for elective patients per week
- The OR capacity needed for emergent patients per week
- The order of the operating room blocks
- The expected length of stay per patient category
- The allowed number of wrong hospitalizations per day

After these values are determined, our mathematical model should be used to receive insight into:

- The OR occupancy per day
- The bed occupancy at different wards per day
- The number of patients without receiving a surgical operation per day
- The bed deficit and the bed surplus per day
- The number of wrong hospitalizations per day

This should finally lead to receiving into the relation between the admission planning and the bed capacity by taking to account the consequences of changing the input parameter values.

### *8.2.2 Other recommendations*

Chapter 3 shows that the clinical pathways of Sittard and Heerlen are different in almost every unit. When patient flows are crossing locations in the future it is recommended to standardize clinical pathways in such a way that the way of working is equal at both locations. So the clinical pathways at both locations should become one clinical pathway for the merged Zuyderland MC.

It is also recommended for the future to use a flexible operating room schedule as used in our mathematical model, since the results of the scenario analysis show that with a flexible OR planning, no bed deficit and no wrong hospitalizations exist at the nursing unit.

Another recommendation is based on the use of chain logistic principles instead of unit logistic principles. It is important to realize that all units within a clinical pathway are connected with each other. So optimizing one unit, does not have mean that the whole process performs better. When the Zuyderland MC wants to manage processes from a network logistics perspective, it is important to consider all specialism and all units together in order to use the benefits of a unit logistics approach combined with the benefits of a chain logistics approach. However, it seems important to first create awareness of the fact that units within a chain are connected to each other than immediately implementing network logistic principles.

The mathematical model should be run for the whole hospital. In this way it is possible to view improvements which are related to the admission planning and the bed capacity for all specialism. The results of the scenario analysis show that in Sittard the number of available beds at the nursing unit can be decreased by two beds, when the mathematical model is run for all specialism those results have more meaning.

The availability of data sets should be improved and the data sets should not only be focused on unit logistic principles. This would make it easier to follow patients between the units in a hospital. It is also recommended to facilitate separate data sets used for financial purposes and logistic purposes. In this way the data used for logistic calculations of capacity constraints should become more meaningful since it can be expected that the data contains less mistakes.

## 8.3 Limitations and suggestions for further research

One limitation of this report can be found in the fact that our mathematical model is only tested for one specialism; however, our mathematical model is based on general principles which makes it easy to use the model also for other specialism. Another limitation of this research can be found in the fact that the surgeons planning is not related to the OR schedule. Since the specialism surgery is merged years ago, all surgeons operate at both locations so it is not possible for them to be at both locations at the same time. Our mathematical model should therefore be used for the creation of tactical plans related to the merged hospital, because when specific surgical operations are always performed at one location, the benefits of a flexible OR schedule should become more visible.

Further research could be focused on the extension of our mathematical model by more units within the clinical pathways. In this way the relation between; for example, the policlinic department, the operation theatre and the wards could be made visible. In this case it might also be possible to take into account the surgeons planning, since surgeons have to first diagnose patients at the policlinic department before treating them at the operation theatre.

## References


Adan, I. et al., 2011. Improving operational effectiveness of tactical master plans for emergency and elective patients under stochastic demand and capacitated resources. *European Journal of Operational Research 213,* pp. 290-308.

Anon., 2014. *Atrium- orbis.* [Online]
Available at: http://www.atrium-orbis.nl/

Bekker, R. & Koeleman, P. M., 2011. Scheduling admissions and reducing variability in bed demand. *Health Care Management Science 14*, pp. 237-249.

Bertrand, W. & Vries, G. d., 2005. Lessons to be learned from operations management. In: *Health Operations Management: Patient Flow Logistics in Health Care.* London: Routledge, pp. 15-39.

Dalgleish, D., 2013. *Create a simple boxplot in Excel.* [Online]
Available at: http://blog.contextures.com/archives/2013/06/11/create-a-simple-box-plot-in-excel/
[Geopend 4 10 2015].

de Bruin, A., Bekker, R., van Zanten, L. & Koole, G., 2010. Dimensioning hospital wards using the Erlang loss model. *Ann Operational Research 178*, pp. 23-43.

Field, A., 2009. Dealing with outliers. In: *Discovering statistics using SPSS.* London: SAGE publications Ltd, p. 153.

Fügener, A. et al., 2014. Master surgery scheduling with consideration of multiple downstream units. *European Journal of Operational Research 239,* pp. 227-236.

Green, L. V., 2004. Capacity planning and management in hospitals. In: *Operations Research and Health Care: A Handbook of Methods and Applications.* sl:Kluwer Academic Publishers, pp. 16-41.

Haraden, C. & Resar, R., 2004. Patient Flow in Hospitals: Understanding and Controlling It Better. *Frontiers of Health Services Management 20, 4*, pp. 3-15.

Hulshof, P. J., 2013. *Integrated Decision Making in Healthcare: An Operations Research and Management Science Perspective,* Enschede: Ipskamp Drukkerijen.

Jack, E. P. & Powers, T. L., 2009. A review and synthesis of demand management, capacity management and performance in healthcare services. *International Journal of Management Reviews 11 (2),* pp. 149-174.

Kumar, S., 2011. Modeling hospital surgical delivery process design using system simulation: Optimizng patient flow and bed capacity as an illustration. *Technology and Health Care 19*, pp. 1-20.

Langabeer II, J. R., 2008. Healthcare Operations Management. In: *Health Care Operations Management: A Quantitative Approach to Business and Logistics.* Texas: Jones and Bartlett Publishers, pp. 3-19.

Langabeer II, J. R., 2008. Optimizing Patient and Process Flows. In: *Health Care Operations Management: A Quantitative Approach to Business and Logistics.* Texas: Jones and Bartlett Publishers, pp. 95-126.

Litvak, E. & Bisognano, M., 2011. More Patients, Less Payment: Increasing Hospital Efficiency In The Aftermath Of Health Reform. *Health Affairs 30, 1*, pp. 76-80.

Ma, G. & Demeulemeester, E., 2013. A Multilevel Integrative Approach to Hospital Case Mix and Capacity Planning. *Computers and Operations Research 40*, pp. 2198-2207.

Merode, G. G. v., Groothuis, S. & Hasman, A., 2004. Enterprise resource planning for hospitals. *International Journal of Medical Informatics 73,* pp. 493-501.

Rechel, B., Wrigth, S., Barlow, J. & McKee, M., 2010. Hospital capacity planning: from measuring stocks to modelling flows. *Bull World Health Organ 88*, pp. 632-636.

Rohleder, T. R., Cooke, D., Rogers, P. & Egginton, J., 2013. Coordinating Health Services: An Operations Management Perspective. In: *Handbook of Healthcare Operations Management.* New York: Springer, pp. 421-444.

Sematech, N., 2013. *What are outliers in the data?.* [Online]
Available at: http://www.itl.nist.gov/div898/handbook/prc/section1/prc16.htm
[Geopend 4 10 2015].

Serendipity, 2010. *The difference between Verification and Validation.* [Online]
Available at: http://www.easterbrook.ca/steve/2010/11/the-difference-between-verification-and-validation/
[Geopend 9 10 2015].

Tànfani, E. & Testi, A., 2012. A simulation-based decision support tool to analyze clinical pathways in hospital. In: *Advanced Decision Making Methods Applied to Health Care.* Milan: Springer, pp. 191-210.

Thompson, S. M., Day, R. & Garfinkel, R., 2013. Improving the Flow of Patients Through Healthcare Organizations. In: *Handbook of Healthcare Operations Management.* New York: Springer, pp. 183-202.

Vissers, J., 2005. Aggregate hospital production and capacity planning. In: *Health Operations Management: Patient Flow Logistics in Health Care.* London: Routledge, pp. 116-146.

Vissers, J. & Beech, R., 2005. Chain logistics: analysis of care chains. In: *Health Operations Management: Patient Flow Logistics in Health Care.* London: Routledge, pp. 70-84.

Vissers, J. & Beech, R., 2005. Health operations management: basic concepts and approaches. In: *Health Operations Management: Patient Flow Logistics in Health Care.* London: Routledge, pp. 39-51.

Vissers, J., Bertrand, W. & Vries, G., 2005. Frameworks for health operations management. In: *Health Operations Management: Patient Flow Logistics in Health Care.* London: Routledge, pp. 84-93.

Vissers, J. M., 1994. *Patient Flow based Allocation of Hospital Resources.* Enschede: Febo.

Worthington, D., 2007. Operational Research Modelling To Support Healthcare Operations Management. In: *Operational Research for Health Policy: Making Better Decisions.* Bern: International Academic Publishers, pp. 11-22.

# Appendices

# A. Outliers

Appendix A starts with a brief introduction to outliers and the treatment of outliers in section A.1. After this, Appendix A continues with the outliers found in the data sets of Sittard and Heerlen and the way of treating them in section A.2.

## A.1 Introduction and treatment of outliers

For the calculation of the length of stay distribution at the IC and NU and the average length of stay at the DC, outliers have to be removed. An outlier can be seen as an observation that is very different from most other observations. Outliers can bias statistics such as the mean. Boxplots can be used in the identification of outliers together with an analytic procedure (Sematech, 2013).

Figure 3 shows a picture of a boxplot which consist of a minimum value, the value of Quartile 1 (Q1), the median, the value of Quartile 3 (Q3) and the maximum. The analytic procedure is based on the difference between Q3 and Q1 which is called the interquartile range (IQR) (Sematech, 2013).

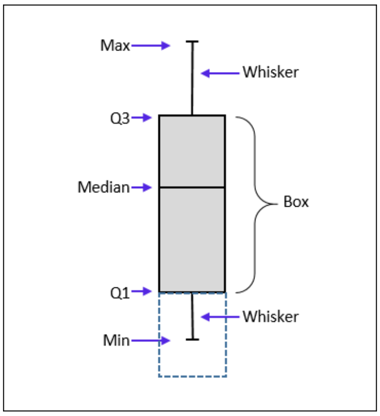


Figure 3: Example of a boxplot (Dalgleish, 2013)

The IQR method distinguishes two types of outliers; mild outliers and extreme outliers. Another distinction is made between upper and lower outliers.

- Upper mild outliers: Value > Q3 + 1.5 IQR
- Lower mild outliers: Value < Q1 – 1.5 IQR
- Upper extreme outliers: Value > Q3 + 3 IQR
- Lower extreme outliers: Value < Q1 – 3 IQR

Outliers which are indicated as extreme outliers should be deleted or replaced, because those values bias the average and standard deviation of the data set (Sematech, 2013). Dealing with outliers can be done in different ways. It is possible to remove the case, to transform the data and to change the score. Removing cases can only be done when there is a good reason to believe that the outlier is not from the population which is intended in the sample. Data can be transformed when outliers skew the distribution. The last option is to change the score of the outliers. In this way only the part of the data which forms an outlier is changed to a score more in line with the rest of the data points. Outliers can be changed in the mean plus two times the standard deviation (Field, 2009).

## A.2 Outliers in the data set of Sittard

For the data set of Sittard outliers are determined by using the IQR method and are corrected by using the mean plus two times the standard deviation. This way of working is used because no data is removed, the data is only changed into values which are more suitable with the rest of the data. The outliers are determined per patient category because the length of stay distribution is also different per patient category. It is important that the “new” value of the outliers is lower than the Q3 + 3 IQR, because otherwise the “new” value is still an outlier. To create such a value, some of the extreme outliers should be removed first, before changing them into the “new” value for the outliers.

### *A.2.1 Onco, long, gastroint. Surgery*

This section is subdivided into the Intensive care, the Nursing unit and the Daycare unit.

#### A.2.1.1 Intensive care

Table 14 is obtained after removing five upper extreme outliers. The value of Q3 + 3 IQR is equal to 309,2000, so everything above this value should be replaced by mean + 2*standard deviation which is equal to 278,6466. However, according to the data it seems better to replace everything above 288, because otherwise one or two values remain in one sub category (between x days and x days) of the length of stay distribution. In total 8 outliers are replaced by the value indicated by outliers in Table 14.

#### A.2.1.2 Nursing unit

After removing one of the upper extreme outliers the values in Table 14 are obtained. The value of Q3 + 3 IQR is equal to 548,7000 everything above this value should be replaced by mean + 2*standard deviation which is equal to 371,4048. According to the data it seems better to replace every value above 528, because otherwise one or two values remain in one sub category (between x days and x days) of the length of stay distribution. In total 15 outliers are replaced by the value indicated by outliers in Table 14.

#### A.2.1.3 Daycare unit

There were two lower extreme outliers, of which one had a very low value and is therefore removed and not replaced. Table 14 shows the values of the DC boxplot and the IQR calculations.

| Labels | IC boxplot | NU boxplot | DC boxplot |
|---|---|---|---|
| Min | 1,0833 | 2,4548 | 3,0167 |
| Q1 | 17,5333 | 28,7667 | 7,5083 |
| Median | 26,3333 | 78,9167 | 8,9833 |
| Q3 | 90,4500 | 158,7500 | 10,4833 |
| Max | 504,1667 | 1102,5000 | 12,4333 |
| IQR | 72,9167 | 129,9833 | 2,9750 |
| Upper mild outliers | 10 | 50 | 0 |
| Lower mild outliers | 0 | 0 | 1 |
| Upper extreme outliers | 3 | 13 | 0 |
| Lower extreme outliers | 0 | 0 | 0 |
| | | | |
| Q1-1,5*IQR | -91,8417 | -166,2083 | 3,0458 |
| Q3+1,5*IQR | 199,8250 | 353,7250 | 14,9458 |
| Q1-3*IQR | -201,2167 | -361,1833 | -1,4167 |
| Q3+3*IQR | 309,2000 | 548,7000 | 19,4083 |
| | | | |
| Average | 75,9505 | 119,3112 | 8,8116 |
| Standard deviation | 101,3481 | 126,0468 | 2,2405 |
| | | | |
| Outliers | 278,6466 | 371,4048 | 13,2926 |

*Table 14: Boxplots Onco, long, gastroint. surgery (Sittard)*

### *A.2.2 Vaat*

This section is subdivided into the Intensive care, the Nursing unit and the Daycare unit.

#### A.2.2.1 Intensive care

After deleting ten upper extreme outliers, the values in Table 15 are obtained. The value of Q3 + 3*IQR equals 44,2750 so everything above this value should be replaced by mean + 2*standard deviation which equals 47,4128. However, according to the data it seems better to replace everything above 72, the variation in the data was very large also after removing those ten cases. When every value above 44,2750 was replaced not much original values remain. The values beneath 72 could all be placed into sub categories of the length of stay distribution with enough values remained per sub category (between x days and x days). For this reason is chosen to diverge from the IQR rule and use our own interpretation of the data. Finally, 11 outliers are replaced by the value indicated by outliers in Table 15.

#### A.2.2.2 Nursing unit

After removing two upper extreme outliers, the values in Table 15 are obtained. The value Q3 + 3 IQR is equal to 656,4125, so every value above this value should be replaced by mean + 2*standard deviation which is equal to 618,2501. However, according to the data it seems better to replace every value above 648. In total 17 outliers are replaced by the value indicated by outliers in Table 15.

#### A.2.2.3 Daycare unit

One lower extreme outlier is removed and not replaced, because of its very low value. Table 15 shows the values of the DC boxplot and the IQR calculations.

| Labels (c=2) | IC boxplot | NU boxplot | DC boxplot |
|---|---|---|---|
| Min | 4,2167 | 2,7500 | 3,0667 |
| Q1 | 20,9083 | 56,9958 | 5,2083 |
| Median | 23,7500 | 121,1083 | 6,0917 |
| Q3 | 26,7500 | 206,8500 | 6,7458 |
| Max | 75,2500 | 1574,7500 | 8,9000 |
| IQR | 5,8417 | 149,8542 | 1,5375 |
| Upper mild outliers | 29 | 34 | 0 |
| Lower mild outliers | 2 | 0 | 0 |
| Upper extreme outliers | 18 | 15 | 0 |
| Lower extreme outliers | 0 | 0 | 0 |
| | | | |
| Q1-1,5*IQR | 12,1458 | -167,7854 | 2,9021 |
| Q3+1,5*IQR | 35,5125 | 431,6313 | 9,0521 |
| Q1-3*IQR | 3,3833 | -392,5667 | 0,5958 |
| Q3+3*IQR | 44,2750 | 656,4125 | 11,3583 |
| | | | |
| Average | 26,4874 | 187,9183 | 5,9912 |
| Standard deviation | 10,4627 | 215,1659 | 1,4585 |
| | | | |
| Outliers | 47,4128 | 618,2501 | 8,9081 |

*Table 15: Boxplots Vaat (sittard)*

### *A.2.3 Trauma*

This section is subdivided into the Intensive care, the Nursing unit and the Daycare unit.

#### A.2.3.1 Intensive care

According to Table 16 no extreme outliers are found in the sub categories of the length of stay distribution.

#### A.2.3.2 Nursing unit

After deleting one upper extreme outlier, the values in Table 16 are obtained. The value of Q3 + 3 IQR equals 533,4406, so every value above this value should be replaced by mean + 2*standard deviation which equals 329,6913. According to the data it seems better to replace every value above 432. In total 4 outliers are replaced by the value indicated by outliers in Table 16.

#### A.2.3.3 Daycare unit

According to Table 16 no extreme outliers are found in the sub categories of the length of stay distribution.

| Labels (c=3) | IC boxplot | NU boxplot | DC boxplot |
|---|---|---|---|
| Min | 1,3000 | 3,0000 | 3,5667 |
| Q1 | 9,2125 | 14,2958 | 5,4500 |
| Median | 14,1833 | 54,1006 | 6,7667 |
| Q3 | 27,4750 | 144,0820 | 8,3667 |
| Max | 60,3500 | 898,3833 | 11,1500 |
| IQR | 18,2625 | 129,7862 | 2,9167 |
| Upper mild outliers | 1 | 10 | 0 |
| Lower mild outliers | 0 | 0 | 0 |
| Upper extreme outliers | 0 | 1 | 0 |
| Lower extreme outliers | 0 | 0 | 0 |
| | | | |
| Q1-1,5*IQR | -18,1813 | -180,3835 | 1,0750 |
| Q3+1,5*IQR | 54,8688 | 338,7613 | 12,7417 |
| Q1-3*IQR | -45,5750 | -375,0627 | -3,3000 |
| Q3+3*IQR | 82,2625 | <u>533,4406</u> | 17,1167 |
| | | | |
| Average | 22,5042 | 96,2194 | 6,9982 |
| Standard deviation | 24,6801 | 116,7360 | 1,9758 |
| | | | |
| Outliers | 71,8644 | <u>329,6913</u> | 10,9498 |

*Table 16: Boxplots Trauma (Sittard)*

### *A.2.4 Algemeen*

This section is subdivided into the Intensive care, the Nursing unit and the Daycare unit.

#### A.2.4.1 Intensive care

Table 17 shows one upper extreme outlier at the IC. The value of Q3 + 3 IQR is equal to 233,7272, so the upper extreme value is replaced by mean + 2*standard deviation which is equal to 300,2000.

#### A.2.4.2 Nursing unit

After removing one upper extreme outlier, the values in Table 17 are obtained. The value of Q3 + 3 IQR equals 326,6833, so every value above this value should be replaced by mean + 2*standard deviation which equals 264,6453. According to the data it seems better to replace every value above 288. In total 15 outliers are replaced by the value indicated by outliers in Table 17.

#### A.2.4.3 Daycare unit

One lower extreme outlier is removed and not replaced, because of its very low value. The other lower mild outliers did not have a value which was biasing the data set, also the upper extreme outlier was not biasing the average length of stay. When there is much dispersion, much outliers are detected. However, not every detected outlier has to be an outlier for the intended use of the data set. Table 17 shows the values of the DC boxplot and the IQR calculations.

| Labels (c=4) | IC boxplot | NU boxplot | DC boxplot |
|---|---|---|---|
| Min | 2,4833 | 1,0333 | 2,4833 |
| Q1 | 14,7667 | 19,9167 | 5,3333 |
| Median | 23,6000 | 29,5000 | 6,1000 |
| Q3 | 86,1250 | 96,6083 | 7,1000 |
| Max | 350,7000 | 732,9167 | 19,8333 |
| IQR | 71,3583 | 76,6917 | 1,7667 |
| Upper mild outliers | 1 | 29 | 13 |
| Lower mild outliers | 0 | 0 | 3 |
| Upper extreme outliers | 1 | 13 | 1 |
| Lower extreme outliers | 0 | 0 | 0 |
| | | | |
| Q1-1,5*IQR | -92,2708 | -95,1208 | 2,6833 |
| Q3+1,5*IQR | 193,1625 | 211,6458 | 9,7500 |
| Q1-3*IQR | -199,3083 | -210,1583 | 0,0333 |
| Q3+3*IQR | 300,2000 | 326,6833 | 12,4000 |
| | | | |
| Average | 65,2430 | 73,0101 | 6,2843 |
| Standard deviation | 84,2421 | 95,8176 | 1,5906 |
| | | | |
| Outliers | 233,7272 | 264,6453 | 9,4656 |

*Table 17: Boxplots Algemeen (Sittard)*

### *A.2.5 Nursing unit without receiving surgical operation*

After deleting two upper extreme outliers, Table 18 is obtained. The value of Q3 + 3 IQR is equal to 495,2833, so every value above this value should be replaced by mean + 2*standard deviation which is equal to 365,3634. According to the data it seems better to replace every value above 480. In the end, 31 outliers are replaced by the value indicated by outliers in Table 18.

| Labels (s=1) | NU boxplot |
|---|---|
| Min | 0,0167 |
| Q1 | 19,9667 |
| Median | 45,9083 |
| Q3 | 138,7958 |
| Max | 841,4333 |
| IQR | 118,8292 |
| Upper mild outliers | 68 |
| Lower mild outliers | 0 |
| Upper extreme outliers | 26 |
| Lower extreme outliers | 0 |
| Q1-1,5*IQR | -158,2771 |
| Q3+1,5*IQR | 317,0396 |
| Q1-3*IQR | -336,5208 |
| Q3+3*IQR | 495,2833 |
| Average | 102,6563 |
| Standard deviation | 131,3535 |
| Outliers | 365,3634 |

*Table 18: Boxplot NU without receiving OR (Sittard)*

*A.2.6 Daycare unit without receiving surgical operation*

After removing one upper extreme outlier, Table 19 is obtained. The value of Q3 + 3 IQR is equal to 9,4625, so every value above this value should be replaced by mean + 2*standard deviation which is equal to 6,8363. In the end, 10 outliers are replaced by the value indicated by outliers in Table 19.

| **Labels (s=2)** | **DC boxplot** |
|---|---|
| Min | 0,3833 |
| Q1 | 2,0958 |
| Median | 2,6333 |
| Q3 | 3,9375 |
| Max | 11,5833 |
| IQR | 1,8417 |
| Upper mild outliers | 43 |
| Lower mild outliers | 0 |
| Upper extreme outliers | 9 |
| Lower extreme outliers | 0 |
| | |
| Q1-1,5*IQR | -0,6667 |
| Q3+1,5*IQR | 6,7000 |
| Q1-3*IQR | -3,4292 |
| Q3+3*IQR | 9,4625 |
| | |
| Average | 3,2787 |
| Standard deviation | 1,7788 |
| | |
| Outliers | 6,8363 |

*Table 19: Boxplot DC without receiving OR (Sittard)*

## A.3 Outliers in the data set of Heerlen

Also for the data set of Heerlen outliers are determined by using the IQR method and are corrected by using the mean plus two times the standard deviation. This way of working is used because no data is removed, the data is only changed into values which are more suitable with the rest of the data. The outliers are determined per patient category because the length of stay distribution is also different per patient category. It is important that the "new" value of the outliers is lower than the Q3 + 3 IQR, because otherwise the "new" value can still be seen as an outlier. To create such a value, some of the extreme outliers should be removed first, before changing them into the "new" value for the outliers.

### *A.3.1 Onco, long, gastroint. Surgery*

This section is subdivided into the Intensive care, the Nursing unit and the Daycare unit.

#### A.3.1.1 Intensive care

Table 20 is obtained after removing twenty upper extreme outliers. The value of Q3 + 3 IQR equals 372,2500, so everything above this value should be replaced by mean + 2*standard deviation which is equal to 369,2158. In total 46 outliers are replaced by the value indicated by outliers in Table 20.

#### A.3.1.2 Nursing unit

After removing thirteen upper extreme outliers the values in Table 20 are obtained. The value of Q3 + 3 IQR is equal to 437,9000 everything above this value should be replaced by mean + 2*standard deviation which is equal to 362,6011. In total 71 outliers are replaced by the value indicated by outliers in Table 20.

#### A.3.1.3 Daycare unit

According to Table 20 no extreme outliers are found in the sub categories of the length of stay distribution.

| Labels (c=1) | Boxplot IC | Boxplot NU | Boxplot DC |
|---|---|---|---|
| Min | 7,2000 | 0,9000 | 2,0000 |
| Q1 | 26,0500 | 27,5000 | 7,0000 |
| Median | 50,2000 | 52,9000 | 8,3000 |
| Q3 | 112,6000 | 130,1000 | 9,7000 |
| Max | 582,9000 | 982,3667 | 14,0000 |
| IQR | 86,5500 | 102,6000 | 2,7000 |
| Upper mild outliers | 23 | 146 | 3 |
| Lower mild outliers | 0 | 0 | 1 |
| Upper extreme outliers | 12 | 58 | 0 |
| Lower extreme outliers | 0 | 0 | 0 |
| Q1-1,5*IQR | -103,7750 | -126,4000 | 2,9500 |
| Q3+1,5*IQR | 242,4250 | 284,0000 | 13,7500 |
| Q1-3*IQR | -233,6000 | -280,3000 | -1,1000 |
| Q3+3*IQR | 372,2500 | 437,9000 | 17,8000 |
| Average | 106,5704 | 105,5583 | 8,2727 |
| Standard deviation | 131,3227 | 128,5214 | 2,1473 |
| Outliers | 369,2158 | 362,6011 | 12,5673 |

*Table 20: Boxplots Onco, long, gastroint. surgery (Heerlen)*

### A.3.2 Vaat

This section is subdivided into the Intensive care, the Nursing unit and the Daycare unit.

#### A.3.2.1 Intensive care

Table 21 is obtained after removing 5 upper extreme outliers. The value of Q3 + 3 IQR is equal to 315,0500, so everything above this value should be replaced by mean + 2*standard deviation which is equal to 247,4012. However, according to the data it seems better to replace everything above 288, because otherwise one or two values remain in one sub category (between x days and x days) of the length of stay distribution. In total 11 outliers are replaced by the value indicated by outliers in Table 21.

#### A.3.2.2 Nursing unit

After removing no upper extreme outliers the values in Table 21 are obtained. The value of Q3 + 3 IQR is equal to 511,9800 everything above this value should be replaced by mean + 2*standard deviation which is equal to 452,3597. According to the data it seems better to replace every value above 504, because otherwise one or two values remain in one sub category (between x days and x days) of the length of stay distribution. In total 25 outliers are replaced by the value indicated by outliers in Table 21.

#### A.3.2.3 Daycare unit

According to Table 21 no extreme outliers are found in the sub categories of the length of stay distribution.

| **Labels (c=2)** | **Boxplot IC** | **Boxplot NU** | **Boxplot DC** |
|---|---|---|---|
| Min | 0,8000 | 0,8000 | 4,6000 |
| Q1 | 26,4500 | 50,3500 | 7,0000 |
| Median | 48,4000 | 97,6000 | 8,5500 |
| Q3 | 98,6000 | 165,7575 | 10,0000 |
| Max | 359,6000 | 1085,8000 | 12,2000 |
| IQR | 72,1500 | 115,4075 | 3,0000 |
| Upper mild outliers | 9 | 49 | 0 |
| Lower mild outliers | 0 | 0 | 0 |
| Upper extreme outliers | 5 | 23 | 0 |
| Lower extreme outliers | 0 | 0 | 0 |
| | | | |
| Q1-1,5*IQR | -81,7750 | -122,7612 | 2,5000 |
| Q3+1,5*IQR | 206,8250 | 338,8687 | 14,5000 |
| Q1-3*IQR | -190,0000 | -295,8725 | -2,0000 |
| Q3+3*IQR | 315,0500 | 511,9800 | 19,0000 |
| | | | |
| Average | 80,7330 | 141,4115 | 8,4083 |
| Standard deviation | 83,3341 | 155,4741 | 2,3471 |
| | | | |
| Outliers | 247,4012 | 452,3597 | 13,1026 |

*Table 21: Boxplots Vaat (Heerlen)*

### *A.3.3 Trauma*

This section is subdivided into the Intensive care, the Nursing unit and the Daycare unit.

#### A.3.3.1 Intensive care

After removing one upper extreme outlier, the values in Table 22 are obtained. The value of Q3 + 3 IQR equals 365,8750, so every value above this value should be replaced by mean + 2*standard deviation which equals 337,1357. According to the data it seems better to replace every value above 360. In total 2 outliers are replaced by the value indicated by outliers in Table 22.

#### A.3.3.2 Nursing unit

The values of Table 22 are obtained without the deletion of upper extreme outliers. The value of Q3 + 3 IQR equals 393,6667, so every value above this value should be replaced by mean + 2*standard deviation which equals 332,2251. According to the data it seems better to replace every value above 384. In total 15 outliers are replaced by the value indicated by outliers in Table 22.

#### A.3.3.3 Daycare unit

According to Table 22 no extreme outliers are found in the sub categories of the length of stay distribution.

| Labels (c=3) | Boxplot IC | Boxplot NU | Boxplot DC |
|---|---|---|---|
| Min | 13,9000 | 2,2000 | 2,8000 |
| Q1 | 35,7750 | 26,6000 | 6,5000 |
| Median | 64,7500 | 77,3186 | 8,0000 |
| Q3 | 118,3000 | 118,3667 | 9,0000 |
| Max | 387,7000 | 867,3000 | 13,0000 |
| IQR | 82,5250 | 91,7667 | 2,5000 |
| Upper mild outliers | 3 | 34 | 2 |
| Lower mild outliers | 0 | 0 | 0 |
| Upper extreme outliers | 1 | 15 | 0 |
| Lower extreme outliers | 0 | 0 | 0 |
| | | | |
| Q1-1,5*IQR | -88,0125 | -111,0500 | 2,7500 |
| Q3+1,5*IQR | 242,0875 | 256,0167 | 12,7500 |
| Q1-3*IQR | -211,8000 | -248,7000 | -1,0000 |
| Q3+3*IQR | <u>365,8750</u> | <u>393,6667</u> | 16,5000 |
| | | | |
| Average | 110,2650 | 102,1790 | 7,9475 |
| Standard deviation | 113,4353 | 115,0230 | 1,9887 |
| | | | |
| Outliers | <u>337,1357</u> | <u>332,2251</u> | 11,9250 |

*Table 22: Boxplots Trauma (Heerlen)*

### *A.3.4 Algemeen*

This section is subdivided into the Intensive care, the Nursing unit and the Daycare unit.

#### A.3.4.1 Intensive care

After deleting four upper extreme outliers, the value in Table 23 are obtained. The value of Q3 + 3 IQR is equal to 299,3000, so every value above this value should be replaced by mean + 2*standard deviation which is equal to 225,5117. According to the data it seems better to replace every value above 264. In the end, 12 outliers are replaced by the value indicated by outliers in Table 23.

#### A.3.4.2 Nursing unit

After removing four upper extreme outliers, the values in Table 23 are obtained. The value of Q3 + 3 IQR equals 293,1000, so every value above this value should be replaced by mean + 2*standard deviation which equals 251,0551. According to the data it seems better to replace every value above 288. In total 31 outliers are replaced by the value indicated by outliers in Table 23.

#### A.3.4.3 Daycare unit

According to Table 23 no extreme outliers are found in the sub categories of the length of stay distribution.

| Labels (c=4) | Boxplot IC | Boxplot NU | Boxplot DC |
|---|---|---|---|
| Min | 13,6000 | 1,7000 | 1,4000 |
| Q1 | 46,1000 | 20,6000 | 5,8000 |
| Median | 69,5000 | 28,3500 | 7,3000 |
| Q3 | 109,4000 | 88,7250 | 9,0000 |
| Max | 241,1000 | 866,5000 | 12,8000 |
| IQR | 63,3000 | 68,1250 | 3,2000 |
| Upper mild outliers | 4 | 55 | 0 |
| Lower mild outliers | 0 | 0 | 0 |
| Upper extreme outliers | 0 | 26 | 0 |
| Lower extreme outliers | 0 | 0 | 0 |
| | | | |
| Q1-1,5*IQR | -48,8500 | -81,5875 | 1,0000 |
| Q3+1,5*IQR | 204,3500 | 190,9125 | 13,8000 |
| Q1-3*IQR | -143,8000 | -183,7750 | -3,8000 |
| Q3+3*IQR | 299,3000 | 293,1000 | 18,6000 |
| | | | |
| Average | 90,1485 | 67,2920 | 7,3872 |
| Standard deviation | 67,6816 | 91,8816 | 1,9321 |
| | | | |
| Outliers | 225,5117 | 251,0551 | 11,2514 |

*Table 23: Boxplots Algemeen (Heerlen)*

### A.3.5 Nursing unit without receiving surgical operation

First of all, all values less than 1 hour are deleted because those values bias the other data. Second, one upper extreme outlier is removed and the values in Table 24 are obtained. The value of Q3 + 3 IQR is equal to 369,1421, so every value above this value should be replaced by mean + 2*standard deviation which is equal to 265,4752. According to the data it seems better to replace every value above 360. In the end, 61 outliers are replaced by the value indicated by outliers in Table 24.

| Labels (s=1) | Boxplot NU |
|---|---|
| Min | 1,0000 |
| Q1 | 24,7526 |
| Median | 41,1000 |
| Q3 | 110,8500 |
| Max | 861,9000 |
| IQR | 86,0974 |
| Upper mild outliers | 154 |
| Lower mild outliers | 0 |
| Upper extreme outliers | 54 |
| Lower extreme outliers | 0 |
| | |
| Q1-1,5*IQR | -104,3934 |
| Q3+1,5*IQR | 239,9960 |
| Q1-3*IQR | -233,5394 |
| Q3+3*IQR | 369,1421 |
| | |
| Average | 79,7491 |
| Standard deviation | 92,8630 |
| | |
| Outliers | 265,4752 |

*Table 24: Boxplot NU without OR (Heerlen)*

### A.3.6 Daycare unit without receiving surgical operation

After removing one incomplete data case, Table 25 is obtained. The value of Q3 + 3 IQR is equal to 7,0000, so every value above this value should be replaced by mean + 2*standard deviation which is equal to 8,0946. However, according to the data it seems better to replace everything above 10, the variation in the data was very large. When every value above 7,0000 was replaced not much original values remain. The values beneath 10 could all be placed into sub categories of the length of stay distribution with enough values remaining per sub category (between x days and x days). For this reason is chosen to diverge from the IQR rule and use our own interpretation of the data. Finally, 7 outliers are replaced by the value indicated by outliers in Table 25.

| Labels (s=2) | Boxplot DC |
|---|---|
| Min | 0,6000 |
| Q1 | 3,0000 |
| Median | 3,5000 |
| Q3 | 4,0000 |
| Max | 13,8000 |
| IQR | 1,0000 |
| Upper mild outliers | 80 |
| Lower mild outliers | 3 |
| Upper extreme outliers | 62 |
| Lower extreme outliers | 0 |
| | |
| Q1-1,5*IQR | 1,5000 |
| Q3+1,5*IQR | 5,5000 |
| Q1-3*IQR | 0,0000 |
| Q3+3*IQR | 7,0000 |
| | |
| Average | 4,0002 |
| Standard deviation | 2,0472 |
| | |
| Outliers | 8,0946 |

*Table 25: Boxplot DC without OR (Heerlen)*

## B. Calculations

In appendix B the calculations behind the values displayed in section 5.3.2 are described. The calculations needed are the same at both locations. So the results of the calculations for Sittard and Heerlen are combined per calculation. Appendix B is structured per parameter calculation in the order of section 5.3.2.

### B.1 Target number of elective patients to be operated during the planning horizon

The target number of elective patients to be operated during the planning horizon is calculated per patient category and per surgery type. It is important to exclude; the urgent patient flow, the patients without a hospitalization period at the surgery department and in the Sittard case also the patients who only have a length of stay at the observatorium.

Table 26 shows the calculation steps; for example, 851 patients of category 1 and surgery type 1 are operated during a year (52 weeks). The planning horizon for Sittard and Heerlen is equal to two weeks, so 851/26 equals 32,7308. With the use of the ROUND function in MS Excel, the numbers in the third column are created and used as the target number of elective patients to be operated during the planning horizon. The results of Heerlen can be found in Table 27.

| Tc,s | Total number in 52 weeks | Total number in 2 weeks | Rounded number in 2 weeks |
|---|---|---|---|
| T1,1 | 851 | 32,7308 | 33 |
| T2,1 | 350 | 13,4615 | 13 |
| T3,1 | 158 | 6,0769 | 6 |
| T4,1 | 289 | 11,1154 | 11 |
| | | | |
| T1,2 | 367 | 14,1154 | 14 |
| T2,2 | 33 | 1,2692 | 1 |
| T3,2 | 90 | 3,4615 | 3 |
| T4,2 | 556 | 21,3846 | 21 |

*Table 26: Calculation of the target number of elective patients operated during the planning horizon (Sittard)*

| Tc,s | Total number in 52 weeks | Total number in 2 weeks | Rounded number in 2 weeks |
|---|---|---|---|
| T1,1 | 1494 | 57,4615 | 57 |
| T2,1 | 450 | 17,3077 | 17 |
| T3,1 | 217 | 8,3462 | 8 |
| T4,1 | 327 | 12,5769 | 13 |
| | | | |
| T1,2 | 381 | 14,6538 | 15 |
| T2,2 | 47 | 1,8077 | 2 |
| T3,2 | 242 | 9,3077 | 9 |
| T4,2 | 998 | 38,3846 | 38 |

*Table 27: Calculation of the target number of elective patients operated during the planning horizon (Heerlen)*

### B.2 Operation durations

The operation durations are calculated per patient category and per surgery type. The operation duration is based on the average of all complete operation durations. Patients without a hospitalization period at the surgery nursing unit or with only a length of stay at the observatorium are excluded from the calculations. In this case the urgent patient flow is included. The average is calculated with the use of the AVERAGE function in MS Excel.

## B.3 Average LOS at the daycare department after surgery and without receiving surgery

After deleting the outliers described in appendix A. Outliers, the average length of stay at the daycare department after surgery and without receiving surgery could be calculated. The average length of stay is equal for every day of the week and is calculated with the use of the AVERAGE function in MS Excel.

## B.4 Maximum capacity at the OR, IC, NU and DC

The maximum OR capacity and the maximum bed capacity at the NU are calculated from the data sets provided by the hospital. The maximum capacity is based on averages because not every month is the same, some months are characterized as reduction periods since the patient demand is much lower in those periods. The maximum OR capacity in Sittard is calculated by the number of weeks containing x number of OR blocks. The division of the OR blocks over the week is not specified and could be changed in the mathematical model.

- Maximum OR capacity Sittard

$((1*16)+(16*24)+(8*26)+(9*25)+(2*15)+(1*27)+(1*28)+(2*19)+(1*18)+(1*20)+(6*23)+(2*17)+(1*22)+(1*11))/52 \approx 24$ OR blocks per week

- Maximum OR capacity Heerlen

The maximum OR capacity in Heerlen was provided by the hospital itself. The average number of OR blocks per week is equal to 38,5; however, 60% of the OR blocks first allocated to Trauma are then allocated to surgery. So in total 38,5 + 0.6*5 = 41,5 OR blocks per week.

The maximum bed capacity in Sittard is provided by the hospital, so no calculations are needed. The maximum bed capacity at the NU and DC in Heerlen is calculated by multiplying the number of months with the number of beds available during that period. The maximum capacity at the IC in Heerlen is the same for every month.

- Maximum bed capacity at the NU Heerlen

$((7*64)+(1*45)+(4*60))/12 \approx 62$

- Maximum bed capacity at the DC Heerlen

$((8*68)+(4*74))/12 = 70$

## B.5 Arrival rates

The calculation of the arrival rates for the urgent patient flow and the patients without receiving a surgical operations is the same for both. The arrival rates are calculated by excluding the patients without a hospitalization period at the surgery nursing unit and patients with only a length of stay at the observatorium.

Table 28 shows the calculation of the arrival rates of the urgent patient flow in Sittard. The first 4 rows show the number of urgent patients arrived on Monday (1) till Sunday (7) over the year 2014. In order to calculate the arrival rate per day, the number of patients arrived during 2014 should be divided by the number of weeks in that year. For example, $\beta 2,2$ is calculated by $4/52 \approx 0{,}0769$. In 2014, there were 53 Wednesdays and 52 of the other days in the week. Table 29 shows the results of the calculations for Heerlen. Table 30 (Sittard) and Table 31 (Heerlen) show the calculations with regard to the arrival rates of patient without receiving a surgical operation. The calculation method is the same as the method used for the calculation of the arrival rate of the urgent patient flow.

| βc,d | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Number of patients 1,d | 16 | 15 | 14 | 23 | 18 | 10 | 22 |
| Number of patients 2,d | 4 | 4 | 4 | 3 | 7 | 1 | 4 |
| Number of patients 3,d | 4 | 10 | 4 | 7 | 12 | 12 | 8 |
| Number of patients 4,d | 21 | 19 | 18 | 13 | 19 | 19 | 12 |
| Number of weekdays | 52 | 52 | 53 | 52 | 52 | 52 | 52 |
| β1,d | 0,3077 | 0,2885 | 0,2642 | 0,4423 | 0,3462 | 0,1923 | 0,4231 |
| β2,d | 0,0769 | 0,0769 | 0,0755 | 0,0577 | 0,1346 | 0,0192 | 0,0769 |
| β3,d | 0,0769 | 0,1923 | 0,0755 | 0,1346 | 0,2308 | 0,2308 | 0,1538 |
| β4,d | 0,4038 | 0,3654 | 0,3396 | 0,2500 | 0,3654 | 0,3654 | 0,2308 |

*Table 28: Calculation arrival rate urgent patient flow (Sittard)*

| βc,d | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Number of patients 1,d | 58 | 83 | 55 | 50 | 64 | 48 | 35 |
| Number of patients 2,d | 32 | 42 | 35 | 40 | 27 | 17 | 11 |
| Number of patients 3,d | 35 | 29 | 37 | 30 | 59 | 51 | 42 |
| Number of patients 4,d | 96 | 88 | 102 | 97 | 110 | 52 | 63 |
| Number of weekdays | 52 | 52 | 53 | 52 | 52 | 52 | 52 |
| β1,d | 1,1154 | 1,5962 | 1,0377 | 0,9615 | 1,2308 | 0,9231 | 0,6731 |
| β2,d | 0,6154 | 0,8077 | 0,6604 | 0,7692 | 0,5192 | 0,3269 | 0,2115 |
| β3,d | 0,6731 | 0,5577 | 0,6981 | 0,5769 | 1,1346 | 0,9808 | 0,8077 |
| β4,d | 1,8462 | 1,6923 | 1,9245 | 1,8654 | 2,1154 | 1,0000 | 1,2115 |

*Table 29: Calculation arrival rate urgent patient flow (Heerlen)*

| h -or,s,d | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Number of patients 1,d | 206 | 146 | 195 | 176 | 143 | 99 | 108 |
| Number of patients 2,d | 206 | 97 | 97 | 82 | 311 | 0 | 0 |
| Number of weekdays | 52 | 52 | 53 | 52 | 52 | 52 | 52 |
| h -or,1,d | 3,9615 | 2,8077 | 3,6792 | 3,3846 | 2,7500 | 1,9038 | 2,0769 |
| h -or,2,d | 3,9615 | 1,8654 | 1,8302 | 1,5769 | 5,9808 | 0 | 0 |

*Table 30: Calculation arrival rate patients without OR (Sittard)*

| h -or,s,d | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Number of patients 1,d | 484 | 441 | 431 | 412 | 445 | 281 | 266 |
| Number of patients 2,d | 116 | 106 | 111 | 134 | 125 | 0 | 0 |
| Number of weekdays | 52 | 52 | 53 | 52 | 52 | 52 | 52 |
| h -or,1,d | 9,3077 | 8,4808 | 8,1321 | 7,9231 | 8,5577 | 5,4038 | 5,1154 |
| h -or,2,d | 2,2308 | 2,0385 | 2,0943 | 2,5769 | 2,4038 | 0 | 0 |

*Table 31: Calculation arrival rate patients without OR (Heerlen)*

## B.6 Probability that an emergent patient arrives during the day

The total number of emergent patients arriving during day and night can be found in Table 28 for Sittard and in Table 29 for Heerlen. This number is equal to 323 for Sittard and equal to 1488 for Heerlen. The OR in Sittard is open from 08:15 – 16:15 for elective patients, so the number of urgent patients arriving in this time slot could affect the planned OR schedule. The OR in Heerlen is open from 08:00 – 17:00; however, there is a separate OR available during the day for the urgent patient flow. The number of urgent patient arriving within the timeslot in Sittard is equal to 145 and in Heerlen is equal to 684. The probability that an emergent patient arrives during the day equals 145/323 ≈ 0,45 for Sittard and equals 684/1488 ≈ 0,46 for Heerlen.

## B.7 Length of stay distributions

Table 32 and Table 34 show the calculation of the length of stay distribution at the IC and NU in Sittard and Heerlen. Table 33 and Table 35 show the calculation of the length of stay at the NU for patients without receiving a surgical operation in Sittard and Heerlen. The length of stay distribution at the IC and NU are related to each other. Table 34 shows; the number of patients at the IC and NU per patient category and surgery type 1, then the number of patients leaving the IC or NU on that day and the last rows are the probabilities that a patient from category c with surgery type 1 stays at the IC or NU on that particular day.

The number of patients at the IC and NU per patient category and surgery type 1 are calculated as follows; the total number of hospitalizations for category 1 in Table 34 is equal to (213+1497) = 1710, 213 patients are hospitalized at the IC after surgery, so 1497 patients are therefore hospitalized at the NU after surgery. The probability that a patient of category 1 with surgery type 1 is at the IC the day of surgery equals (213/1710) ≈ 0,1246 and the probability that a patient of category 1 with surgery type 1 is at the NU the day of surgery equals (1497/1710) ≈ 0,8754. Then at day 1, 31 patients of category 1 with surgery type 1 are leaving the IC which means that those patients have to be hospitalized at the NU. At the NU 246 patients of category 1 and surgery type 1 are leaving the nursing unit. So at day 1 there are (213-31) = 182 patients of category 1 at the IC and ((1497+31) – 246) = 1282 patients of category 1 and surgery type 1 at the NU. This means that at day 1 the probability that a patient of category 1 with surgery type 1 is at the IC equals (182/1710) ≈ 0,1064 and the probability the such a patient is at the NU equals (1282/1710) ≈ 0,7497. The rest of the calculations are done in the same way.

The number of patients hospitalized at the NU without receiving a surgical operation is calculated as follow; Table 35 shows that the total number of hospitalizations at the NU on day 0 (day of hospitalization) equals 2760, so the probability that a patient within this category is at the NU on day 0 equals (2760/2760) = 1. At the day 1, 625 patients are leaving, so at this day (2760-625) = 2135 patients are still hospitalized at the NU. The probability which is concerned with this number of patients equals (2135/2760) ≈ 0,7736.

| P w,c,1,d | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of patients ic,1,1,d | 74 | 41 | 26 | 23 | 21 | 19 | 17 | 16 | 15 | 15 | 12 | 10 | 0 | | | | | | | | | | | | | | | |
| Number of patients nu,1,1,d | 808 | 753 | 539 | 463 | 390 | 303 | 237 | 183 | 137 | 117 | 100 | 88 | 83 | 69 | 59 | 48 | 28 | 19 | 11 | 7 | 5 | 2 | 0 | | | | | |
| # patients leaving ic,1,1,d | 33 | 15 | 3 | 2 | 2 | 2 | 1 | 1 | 0 | 3 | 2 | 10 | 0 | | | | | | | | | | | | | | | |
| # patients leaving nu,1,1,d | 88 | 229 | 79 | 75 | 89 | 68 | 55 | 47 | 20 | 20 | 14 | 15 | 14 | 10 | 11 | 20 | 9 | 8 | 4 | 2 | 3 | 2 | 0 | | | | | |
| P ic,1,1,d | 0,0839 | 0,0465 | 0,0295 | 0,0261 | 0,0238 | 0,0215 | 0,0193 | 0,0181 | 0,0170 | 0,0170 | 0,0136 | 0,0113 | 0 | | | | | | | | | | | | | | | |
| P nu,1,1,d | 0,9161 | 0,8537 | 0,6111 | 0,5249 | 0,4422 | 0,3435 | 0,2687 | 0,2075 | 0,1553 | 0,1327 | 0,1134 | 0,0998 | 0,0941 | 0,0782 | 0,0669 | 0,0544 | 0,0317 | 0,0215 | 0,0125 | 0,0079 | 0,0057 | 0,0023 | 0 | | | | | |
| Number of patients ic,2,1,d | 209 | 101 | 8 | 0 | | | | | | | | | | | | | | | | | | | | | | | | |
| Number of patients nu,2,1,d | 106 | 190 | 246 | 220 | 185 | 161 | 129 | 98 | 87 | 79 | 72 | 68 | 64 | 61 | 53 | 50 | 43 | 41 | 36 | 33 | 30 | 28 | 25 | 23 | 21 | 21 | 4 | 0 |
| # patients leaving ic,2,1,d | 108 | 93 | 8 | 0 | | | | | | | | | | | | | | | | | | | | | | | | |
| # patients leaving nu,2,1,d | 24 | 37 | 34 | 35 | 24 | 32 | 31 | 11 | 8 | 7 | 4 | 4 | 3 | 8 | 3 | 7 | 2 | 5 | 3 | 3 | 2 | 3 | 2 | 2 | 0 | 17 | 4 | 0 |
| P ic,2,1,d | 0,6635 | 0,3206 | 0,0254 | 0 | | | | | | | | | | | | | | | | | | | | | | | | |
| P nu,2,1,d | 0,3365 | 0,6032 | 0,7810 | 0,6984 | 0,5873 | 0,5111 | 0,4095 | 0,3111 | 0,2762 | 0,2508 | 0,2286 | 0,2159 | 0,2032 | 0,1937 | 0,1683 | 0,1587 | 0,1365 | 0,1302 | 0,1143 | 0,1048 | 0,0952 | 0,0889 | 0,0794 | 0,0730 | 0,0667 | 0,0667 | 0,0127 | 0 |
| Number of patients ic,3,1,d | 4 | 1 | 1 | 0 | | | | | | | | | | | | | | | | | | | | | | | | |
| Number of patients nu,3,1,d | 205 | 129 | 109 | 93 | 78 | 67 | 54 | 41 | 31 | 25 | 19 | 17 | 15 | 11 | 7 | 7 | 5 | 1 | 0 | | | | | | | | | |
| # patients leaving ic,3,1,d | 3 | 0 | 1 | 0 | | | | | | | | | | | | | | | | | | | | | | | | |
| # patients leaving nu,3,1,d | 79 | 20 | 17 | 15 | 11 | 13 | 13 | 10 | 6 | 6 | 2 | 2 | 4 | 4 | 0 | 2 | 4 | 1 | 0 | | | | | | | | | |
| P ic,3,1,d | 0,0191 | 0,0048 | 0,0048 | 0 | | | | | | | | | | | | | | | | | | | | | | | | |
| P nu,3,1,d | 0,9809 | 0,6172 | 0,5215 | 0,4450 | 0,3732 | 0,3206 | 0,2584 | 0,1962 | 0,1483 | 0,1196 | 0,0909 | 0,0813 | 0,0718 | 0,0526 | 0,0335 | 0,0335 | 0,0239 | 0,0048 | 0 | | | | | | | | | |
| Number of patients ic,4,1,d | 19 | 9 | 7 | 6 | 5 | 3 | 2 | 2 | 1 | 1 | 0 | | | | | | | | | | | | | | | | | |
| Number of patients nu,4,1,d | 369 | 242 | 158 | 125 | 98 | 75 | 50 | 38 | 33 | 28 | 24 | 17 | 0 | | | | | | | | | | | | | | | |
| # patients leaving ic,4,1,d | 10 | 2 | 1 | 1 | 2 | 1 | 0 | 1 | 0 | 1 | 0 | | | | | | | | | | | | | | | | | |
| # patients leaving nu,4,1,d | 137 | 86 | 34 | 28 | 25 | 26 | 12 | 6 | 5 | 5 | 7 | 17 | 0 | | | | | | | | | | | | | | | |
| P ic,4,1,d | 0,0490 | 0,0232 | 0,0180 | 0,0155 | 0,0129 | 0,0077 | 0,0052 | 0,0052 | 0,0026 | 0,0026 | 0 | | | | | | | | | | | | | | | | | |
| P nu,4,1,d | 0,9510 | 0,6237 | 0,4072 | 0,3222 | 0,2526 | 0,1933 | 0,1289 | 0,0979 | 0,0851 | 0,0722 | 0,0619 | 0,0438 | 0 | | | | | | | | | | | | | | | |

*Table 32: Calculation length of stay distribution IC and NU (Sittard)*

| P nu -or,1,d | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # patients nu - or,1,d | 1073 | 767 | 534 | 441 | 348 | 301 | 249 | 208 | 176 | 151 | 120 | 101 | 84 | 74 | 65 | 53 | 17 | 10 | 8 | 5 | 0 |
| # patients leaving nu,1,d | 306 | 233 | 93 | 93 | 47 | 52 | 41 | 32 | 25 | 31 | 19 | 17 | 10 | 9 | 12 | 36 | 7 | 2 | 3 | 5 | 0 |
| P nu, -or,1,d | 1 | 0,7148 | 0,4977 | 0,4110 | 0,3243 | 0,2805 | 0,2321 | 0,1938 | 0,1640 | 0,1407 | 0,1118 | 0,0941 | 0,0783 | 0,0690 | 0,0606 | 0,0494 | 0,0158 | 0,0093 | 0,0075 | 0,0047 | 0 |

*Table 33: Calculation length of stay at NU without OR (Sittard)*

| P w,c,1,d | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of patients ic,1,1,d | 213 | 182 | 131 | 104 | 90 | 74 | 70 | 67 | 64 | 63 | 59 | 56 | 55 | 52 | 49 | 48 | 0 | | | | | |
| Number of patients nu,1,1,d | 1497 | 1282 | 817 | 667 | 539 | 448 | 339 | 262 | 221 | 174 | 145 | 122 | 102 | 82 | 69 | 56 | 21 | 12 | 3 | 0 | | |
| # patients leaving ic,1,1,d | 31 | 51 | 27 | 14 | 16 | 4 | 3 | 3 | 1 | 4 | 3 | 1 | 3 | 3 | 1 | 48 | 0 | | | | | |
| # patients leaving nu,1,1,d | 246 | 516 | 177 | 142 | 107 | 113 | 80 | 44 | 48 | 33 | 26 | 21 | 23 | 16 | 14 | 83 | 9 | 9 | 3 | 0 | | |
| P ic,1,1,d | 0,1246 | 0,1064 | 0,0766 | 0,0608 | 0,0526 | 0,0433 | 0,0409 | 0,0392 | 0,0374 | 0,0368 | 0,0345 | 0,0327 | 0,0322 | 0,0304 | 0,0287 | 0,0281 | 0 | | | | | |
| P nu,1,1,d | 0,8754 | 0,7497 | 0,4778 | 0,3901 | 0,3152 | 0,2620 | 0,1982 | 0,1532 | 0,1292 | 0,1018 | 0,0848 | 0,0713 | 0,0596 | 0,0480 | 0,0404 | 0,0327 | 0,0123 | 0,0070 | 0,0018 | 0 | | |
| Number of patients ic,2,1,d | 120 | 98 | 67 | 40 | 36 | 27 | 24 | 20 | 18 | 14 | 13 | 0 | | | | | | | | | | |
| Number of patients nu,2,1,d | 412 | 411 | 338 | 310 | 236 | 182 | 136 | 106 | 77 | 69 | 61 | 72 | 67 | 59 | 49 | 47 | 47 | 38 | 35 | 3 | 2 | 0 |
| # patients leaving ic,2,1,d | 22 | 31 | 27 | 4 | 9 | 3 | 4 | 2 | 4 | 1 | 13 | 0 | | | | | | | | | | |
| # patients leaving nu,2,1,d | 23 | 104 | 55 | 78 | 63 | 49 | 34 | 31 | 12 | 9 | 2 | 5 | 8 | 10 | 2 | 0 | 9 | 3 | 32 | 1 | 2 | 0 |
| P ic,2,1,d | 0,2256 | 0,1842 | 0,1259 | 0,0752 | 0,0677 | 0,0508 | 0,0451 | 0,0376 | 0,0338 | 0,0263 | 0,0244 | 0 | | | | | | | | | | |
| P nu,2,1,d | 0,7744 | 0,7726 | 0,6353 | 0,5827 | 0,4436 | 0,3421 | 0,2556 | 0,1992 | 0,1447 | 0,1297 | 0,1147 | 0,1353 | 0,1259 | 0,1109 | 0,0921 | 0,0883 | 0,0883 | 0,0714 | 0,0658 | 0,0056 | 0,0038 | 0 |
| Number of patients ic,3,1,d | 21 | 17 | 14 | 9 | 8 | 6 | 6 | 5 | 5 | 5 | 4 | 4 | 4 | 3 | 3 | 0 | | | | | | |
| Number of patients nu,3,1,d | 436 | 346 | 269 | 225 | 167 | 105 | 80 | 62 | 52 | 46 | 31 | 29 | 27 | 22 | 3 | 2 | 0 | | | | | |
| # patients leaving ic,3,1,d | 4 | 3 | 5 | 1 | 2 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 3 | 0 | | | | | | |
| # patients leaving nu,3,1,d | 94 | 80 | 49 | 59 | 64 | 25 | 19 | 10 | 6 | 16 | 2 | 2 | 6 | 19 | 4 | 2 | 0 | | | | | |
| P ic,3,1,d | 0,0460 | 0,0372 | 0,0306 | 0,0197 | 0,0175 | 0,0131 | 0,0131 | 0,0109 | 0,0109 | 0,0109 | 0,0088 | 0,0088 | 0,0088 | 0,0066 | 0,0066 | 0 | | | | | | |
| P nu,3,1,d | 0,9540 | 0,7571 | 0,5886 | 0,4923 | 0,3654 | 0,2298 | 0,1751 | 0,1357 | 0,1138 | 0,1007 | 0,0678 | 0,0635 | 0,0591 | 0,0481 | 0,0066 | 0,0044 | 0 | | | | | |
| Number of patients ic,4,1,d | 42 | 39 | 32 | 25 | 20 | 16 | 16 | 15 | 13 | 11 | 1 | 0 | | | | | | | | | | |
| Number of patients nu,4,1,d | 846 | 511 | 295 | 236 | 185 | 143 | 94 | 66 | 44 | 34 | 37 | 5 | 0 | | | | | | | | | |
| # patients leaving ic,4,1,d | 3 | 7 | 7 | 5 | 4 | 0 | 1 | 2 | 2 | 10 | 1 | 0 | | | | | | | | | | |
| # patients leaving nu,4,1,d | 338 | 223 | 66 | 56 | 46 | 49 | 29 | 24 | 12 | 7 | 33 | 5 | 0 | | | | | | | | | |
| P ic,4,1,d | 0,0473 | 0,0439 | 0,0360 | 0,0282 | 0,0225 | 0,0180 | 0,0180 | 0,0169 | 0,0146 | 0,0124 | 0,0011 | 0 | | | | | | | | | | |
| P nu,4,1,d | 0,9527 | 0,5755 | 0,3322 | 0,2658 | 0,2083 | 0,1610 | 0,1059 | 0,0743 | 0,0495 | 0,0383 | 0,0417 | 0,0056 | 0 | | | | | | | | | |

*Table 34: Calculation length of stay distribution IC and NU (Heerlen)*

| P nu -or,1,d | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # patients nu - or,1,d | 2760 | 2135 | 1234 | 968 | 768 | 612 | 458 | 344 | 258 | 201 | 155 | 129 | 47 | 26 | 12 | 0 |
| # patients leaving nu,1,d | 625 | 901 | 266 | 200 | 156 | 154 | 114 | 86 | 57 | 46 | 26 | 82 | 21 | 14 | 12 | 0 |
| P nu, -or,1,d | 1 | 0,7736 | 0,4471 | 0,3507 | 0,2783 | 0,2217 | 0,1659 | 0,1246 | 0,0935 | 0,0728 | 0,0562 | 0,0467 | 0,0170 | 0,0094 | 0,0043 | 0 |

*Table 35: Calculation length of stay at the NU without OR (Heerlen)*

### B.8 The allowed number of wrong hospitalizations

The allowed number of wrong hospitalizations is based on data provided by the hospitals about patients hospitalized under the specialism surgery at another nursing unit than the surgery nursing unit. The number of wrong hospitalizations in 2014 in Sittard was equal to 768 and the number of wrong hospitalizations in 2014 in Heerlen was equal to 1470. Those numbers for 2014 are divided by 26 to determine the number of wrong hospitalizations within the planning horizon. This number can be seen as the allowed number of wrong hospitalizations, which is equal for Sittard to (768/26) ≈ 30 in two weeks and (30/14) ≈ 2 per day. The allowed number of wrong hospitalizations in Heerlen is equal to (1470/26) ≈ 57 in two weeks and (57/14) ≈ 4 per day.

## C. Model results Sittard

This appendix shows the results of the model testing and the scenario analysis for the situation in Sittard. The first table in every scenario shows the solver solution with the lowest objective function value. The solver solution contains a division of the elective patients in the OR schedule within the planning horizon of 2 weeks (green). The first table also shows the consequences of the OR schedule on the bed occupancy (bed deficit, bed surplus and number of wrong hospitalizations). The second table shows the OR occupancy and the bed occupancy at the IC, NU and DC. Beneath examples are given of the calculation of the OR occupancy and the bed occupancy at the IC, NU and DC. The numbers in the examples are used from Table 36. The explanation apply to all tables following in this appendix.

- Calculation OR occupancy

OR occupancy = required capacity / max available OR capacity

OR occupancy = 23,2162 / 24

OR occupancy = 0,9673

- Calculation bed occupancy IC

Bed occupancy IC = expected number of beds IC / max available bed capacity IC

Bed occupancy IC = 2,5555 / 12

Bed occupancy IC = 0,2130

- Calculation bed occupancy NU

Bed occupancy NU = expected number of beds NU/ max available bed capacity NU

Bed occupancy NU = 36,0828 / 45

Bed occupancy NU = 0,8018

- Calculation bed occupancy DC

Bed occupancy DC = expected number of hours DC / max available hours DC

Bed occupancy DC = 23,5560 / 600

Bed occupancy DC = 0,0393

The values used for the OR occupancy and the bed occupancy at the IC, NU and DC in the main text are based on average values and can be found in every second table in the last column.

Testing phase

| Variable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | SUM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X 1,1,d | 6,647448498 | 4,093779831 | 1,300922614 | 2,008529531 | 2,737370554 | | | 3,187993965 | 5,02325923 | 2,998452693 | 0,00147394 | 4,000769144 | | | 32 |
| X 2,1,d | 2,02314452 | 1,618945474 | 2 | 0 | 1,239025251 | | | 1,17223795 | 1,791183424 | 0,069597012 | 1,001350408 | 1,08451596 | | | 12 |
| X 3,1,d | 0 | 0,14133534 | 0 | 0 | 0 | | | 3,25996052 | 1,54943492 | 0,048331433 | 1,000937786 | 0 | | | 6 |
| X 4,1,d | 0 | 5,252188833 | 0,623834113 | 0,623834113 | 0 | | | 2,728512221 | 0,104678108 | 0,042297784 | 1,624654827 | 0 | | | 11 |
| X1,2,d | 1,014873298 | 0,397751203 | 0 | 1 | 3,510976921 | | | 1,110684793 | 1,508435996 | 0,044724934 | 3,000867809 | 3,411685046 | | | 15 |
| X2,2,d | 0 | 0,101187803 | 0,384541372 | 0 | 0 | | | 0,085633822 | 0,393363136 | 0,034602468 | 0,0006714 | 0 | | | 1 |
| X3,2,d | 0,011398723 | 0,386709492 | 1 | 0 | 0 | | | 1,107612145 | 0,494321637 | 0,999114285 | 0,000843718 | 0 | | | 4 |
| X4,2,d | 0,261060533 | 0,289049703 | 4 | 7 | 0 | | | 0,080435726 | 0,369485429 | 5,999337964 | 4,000630645 | 0 | | | 22 |
| δ- ic,d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| δ- nu,d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| δ- dc,d | 0 | 0 | 0 | 0 | 0 | | | 0 | 0 | 0 | 0 | 0 | | | 0 |
| δ+ ic,d | -9 | -9 | -9 | -10 | -10 | -11 | -11 | -10 | -9 | -10 | -10 | -10 | -11 | -11 | |
| δ+ nu,d | -7 | 0 | -1 | -2 | -3 | -8 | -12 | -4 | -2 | -2 | -2 | -3 | -7 | -11 | |
| δ+ dc,d | -48 | -49 | -47 | -45 | -46 | | | -47 | -48 | -46 | -45 | -46 | | | |
| SUM surplus | 1920 | 1740 | 1710 | 1710 | 1770 | 570 | 690 | 1830 | 1770 | 1740 | 1710 | 1770 | 540 | 660 | 20130 |
| δ+ nu hz,d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| SUM wrong hz | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oc,s*Xc,s,d + Oc,1*qc,d*βc,d (required) | 23,2162 | 23,2522 | 15,1267 | 15,2910 | 15,4006 | | | 23,2162 | 23,2522 | 16,0000 | 15,2910 | 17,9965 | | | |
| C orblock,d * L orblock (max available capacity) | 24 | 24 | 16 | 16 | 16 | | | 24 | 24 | 16 | 16 | 16 | | | |
| OR occupancy | 0,9673 | 0,9688 | 0,9454 | 0,9557 | 0,9625 | | | 0,9673 | 0,9688 | 1,0000 | 0,9557 | 1,1248 | | | 0,9816 |
| Expected number of beds ic | 2,5555 | 3,2194 | 3,0691 | 1,8367 | 2,1123 | 1,3266 | 0,7910 | 1,9182 | 2,8891 | 1,8580 | 1,7693 | 2,2675 | 1,2390 | 0,7345 | |
| Patients hospitalized during current cycle at IC | 1,9982 | 2,7807 | 2,7024 | 1,5130 | 1,8343 | 1,1200 | 0,6600 | 1,8420 | 2,8294 | 1,8500 | 1,7645 | 2,2675 | 1,2390 | 0,7345 | |
| Patients hospitalized in earlier cycles at IC | 0,5573 | 0,4388 | 0,3667 | 0,3238 | 0,2780 | 0,2066 | 0,1310 | 0,0762 | 0,0597 | 0,0079 | 0,0048 | | | | |
| C ic,d*R ic,d (max available capacity) | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | |
| Bed occupancy IC | 0,2130 | 0,2683 | 0,2558 | 0,1531 | 0,1760 | 0,1105 | 0,0659 | 0,1598 | 0,2408 | 0,1548 | 0,1474 | 0,1890 | 0,1032 | 0,0612 | 0,1642 |
| Expected number of beds nu | 36,0828 | 43,4577 | 41,6927 | 40,5946 | 39,9254 | 35,3488 | 31,4458 | 39,1852 | 41,4725 | 41,1652 | 40,7135 | 40,4112 | 36,3230 | 31,9141 | |
| Patients hospitalized during current cycle at NU | 11,4992 | 23,3984 | 25,3491 | 27,2494 | 28,9469 | 26,3025 | 23,8705 | 32,8250 | 36,1785 | 36,7692 | 37,2035 | 37,5974 | 34,1665 | 30,3410 | |
| Patients hospitalized in earlier cycles at NU | 24,5835 | 20,0593 | 16,3436 | 13,3452 | 10,9785 | 9,0464 | 7,5753 | 6,3602 | 5,2941 | 4,3959 | 3,5100 | 2,8139 | 2,1565 | 1,5732 | |
| C nu,d,hz * R nu,d (max available capacity) | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | |
| Bed occupancy NU | 0,8018 | 0,9657 | 0,9265 | 0,9021 | 0,8872 | 0,7855 | 0,6988 | 0,8708 | 0,9216 | 0,9148 | 0,9047 | 0,8980 | 0,8072 | 0,7092 | 0,8567 |
| Expected number of hours dc | 23,5560 | 14,7128 | 40,4563 | 58,0886 | 50,5248 | | | 31,4846 | 27,5835 | 51,3517 | 56,9611 | 49,6433 | | | |
| Expected number of beds dc | 1,9630 | 1,2261 | 3,3714 | 4,8407 | 4,2104 | | | 2,6237 | 2,2986 | 4,2793 | 4,7468 | 4,1369 | | | |
| C dc,d * R dc,d (max available capacity) | 600 | 600 | 600 | 600 | 600 | | | 600 | 600 | 600 | 600 | 600 | | | |
| Bed occupancy DC | 0,0393 | 0,0245 | 0,0674 | 0,0968 | 0,0842 | | | 0,0525 | 0,0460 | 0,0856 | 0,0949 | 0,0827 | | | 0,0674 |

*Table 36: Model testing results (Sittard)*

**Scenario 1: Changing the reserved capacity for emergent patients**

The maximum number of beds available at the nursing unit equals 43 and the allowed number of wrong hospitalizations equals 2 per day, so the bed capacity per day is equal to 45. The reason why the solution in the testing phase does not contain integer values should be found in something different than the available bed capacity. It could be possible; for example, that something is wrong with the available OR capacity.

The time needed for the urgent patient flow arriving during the day is equal to $\sum_{c \in N} \sum_{s \in S} O_{c,s} q_{c,d} \beta_{c,d}$ = (2*(0,7162+0,7522+0,6267+0,7910+0,9006)) = 7,5734 hours in two weeks. The time reserved per day for the urgent patient flow equals 1,5 hours, this is (1,5 *10) = 15 hours in two weeks.

The OR capacity needed to treat all elective patients is equal to:

((32*2,4412)+(12*2,2366)+(6*1,5532)+(11*1,3593)+(15*1,4373)+(1*1,1120)+(4*1,3974)+(22*1,0445)) = 180,4692 hours in two weeks.

Every week 24 OR blocks are available to treat all elective and emergent patients. So the available OR capacity per week is equal to (24*4) = 96 hours, and in two week equal to (2*96) = 192 hours. When 15 hours in two weeks are reserved for the urgent patient flow, (192-15) = 177 hours in two weeks remain for the elective patients. This is not enough to treat all elective patients (177 < 180,4692), so this could be the reason why no solution with integer values existed in the model testing phase.

So by changing the reserved capacity for the emergent patients to one hour per day instead of 1,5 hours per day, the reserved capacity for the urgent patient flow equals (1*10) = 10 hours in two weeks which is larger than 7,5724 hours in two weeks needed to treat the urgent patient flow. The OR capacity remaining for the elective patient flow equals (192-10) = 182 hours in two weeks, which is enough to treat the elective patient flow (182 > 180,4692).

The OR capacity needed for the urgent patient flow together with the elective patient flow should fit with the total OR capacity available per week. So every week 24 OR blocks are available, which equals (2(24*4)) = 192 hours in two weeks. The OR capacity needed for the urgent patient flow and the elective patient flow equals (7,5734+180,4692) = 188,0426. So it is not possible to decrease the maximum OR capacity with one OR block (192 – 188,0426) = 3,9574 < 4 hours.

The reserved capacity for the urgent patient flow is changed to one hour per day, the maximum bed capacity at the nursing unit is still equal to 43, the allowed number of wrong hospitalizations is equal to 2 and the order of the OR blocks is equal to 6,6,4,4,4 (Monday - Friday). It can be expected that the solution does contain integer values, since the OR capacity calculated above should be enough to treat all patients.

## Scenario 1: Changing the reserved capacity for emergent patients

| Variable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | SUM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X 1,1,d | 7 | 2 | 0 | 2 | 0 | | | 8 | 8 | 5 | 0 | 0 | | | 32 |
| X 2,1,d | 0 | 2 | 4 | 0 | 6 | | | 0 | 0 | 0 | 0 | 0 | | | 12 |
| X 3,1,d | 0 | 0 | 0 | 0 | 0 | | | 0 | 0 | 0 | 0 | 6 | | | 6 |
| X 4,1,d | 0 | 10 | 0 | 0 | 0 | | | 1 | 0 | 0 | 0 | 0 | | | 11 |
| X1,2,d | 1 | 0 | 2 | 6 | 1 | | | 0 | 2 | 1 | 0 | 2 | | | 15 |
| X2,2,d | 0 | 0 | 0 | 0 | 0 | | | 0 | 0 | 1 | 0 | 0 | | | 1 |
| X3,2,d | 0 | 0 | 0 | 1 | 0 | | | 0 | 0 | 0 | 1 | 2 | | | 4 |
| X4,2,d | 4 | 0 | 3 | 0 | 0 | | | 2 | 0 | 0 | 13 | 0 | | | 22 |
| δ- ic,d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| δ- nu,d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| δ- dc,d | 0 | 0 | 0 | 0 | 0 | | | 0 | 0 | 0 | 0 | 0 | | | 0 |
| δ+ ic,d | -11 | -9 | -8 | -10 | -7 | -9 | -11 | -11 | -10 | -11 | -11 | -11 | -11 | -11 | |
| δ+ nu,d | -8 | 0 | -3 | -4 | -4 | -7 | -10 | -3 | 0 | 0 | -3 | -2 | -8 | -12 | |
| δ+ dc,d | -46 | -49 | -46 | -45 | -48 | | | -48 | -48 | -48 | -42 | -46 | | | |
| SUM surplus | 1950 | 1740 | 1710 | 1770 | 1770 | 480 | 630 | 1860 | 1740 | 1770 | 1680 | 1770 | 570 | 690 | 20130 |
| δ+ nu hz,d | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | |
| SUM wrong hz | 0 | 70 | 0 | 0 | 0 | 0 | 0 | 0 | 70 | 70 | 0 | 0 | 0 | 0 | 210 |

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | SUM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oc,s*Xc,s,d + Oc,1*qc,d*βc,d (required) | 23,4199 | 23,7008 | 15,5812 | 15,6946 | 15,7575 | | | 23,6941 | 23,1564 | 15,3820 | 15,7669 | 15,8892 | | | |
| C orblock,d * L orblock (max available capacity) | 24 | 24 | 16 | 16 | 16 | | | 24 | 24 | 16 | 16 | 16 | | | |
| OR occupancy | 0,9758 | 0,9875 | 0,9738 | 0,9809 | 0,9848 | | | 0,9873 | 0,9649 | 0,9614 | 0,9854 | 0,9931 | | | 0,9795 |
| Expected number of beds ic | 1,2581 | 2,9245 | 4,4189 | 2,4781 | 5,1073 | 2,6783 | 0,7354 | 1,2208 | 1,5564 | 1,4897 | 1,1089 | 1,0882 | 0,7961 | 0,7255 | |
| Patients hospitalized during current cycle at IC | 0,6854 | 2,4554 | 3,9830 | 2,0901 | 4,7771 | 2,4830 | 0,6498 | 1,1991 | 1,5421 | 1,4818 | 1,1041 | 1,0882 | 0,7961 | 0,7255 | |
| Patients hospitalized in earlier cycles at IC | 0,5727 | 0,4691 | 0,4360 | 0,3880 | 0,3302 | 0,1953 | 0,0856 | 0,0217 | 0,0143 | 0,0079 | 0,0048 | | | | |
| C ic,d*R ic,d (max available capacity) | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | |
| Bed occupancy IC | 0,1048 | 0,2437 | 0,3682 | 0,2065 | 0,4256 | 0,2232 | 0,0613 | 0,1017 | 0,1297 | 0,1241 | 0,0924 | 0,0907 | 0,0663 | 0,0605 | 0,1642 |
| Expected number of beds nu | 34,8897 | 44,4986 | 40,2227 | 39,3021 | 38,7161 | 35,7610 | 33,4055 | 40,2226 | 43,8509 | 44,3345 | 39,8229 | 41,2171 | 35,0410 | 30,7958 | |
| Patients hospitalized during current cycle at NU | 11,1414 | 25,0658 | 24,1888 | 26,0048 | 27,7592 | 26,6224 | 25,7662 | 33,7914 | 38,4630 | 39,9560 | 36,3880 | 38,5888 | 32,9415 | 29,2349 | |
| Patients hospitalized in earlier cycles at NU | 23,7483 | 19,4328 | 16,0338 | 13,2973 | 10,9569 | 9,1385 | 7,6393 | 6,4311 | 5,3880 | 4,3785 | 3,4349 | 2,6282 | 2,0995 | 1,5609 | |
| C nu,d,hz * R nu,d (max available capacity) | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | |
| Bed occupancy NU | 0,7753 | 0,9889 | 0,8938 | 0,8734 | 0,8604 | 0,7947 | 0,7423 | 0,8938 | 0,9745 | 0,9852 | 0,8850 | 0,9159 | 0,7787 | 0,6844 | 0,8604 |
| Expected number of hours dc | 46,9033 | 6,0376 | 42,5811 | 65,3942 | 28,2346 | | | 25,4240 | 23,7918 | 20,7830 | 94,0459 | 51,1673 | | | |
| Expected number of beds dc | 3,9086 | 0,5031 | 3,5484 | 5,4495 | 2,3529 | | | 2,1187 | 1,9826 | 1,7319 | 7,8372 | 4,2639 | | | |
| C dc,d * R dc,d (max available capacity) | 600 | 600 | 600 | 600 | 600 | | | 600 | 600 | 600 | 600 | 600 | | | |
| Bed occupancy DC | 0,0782 | 0,0101 | 0,0710 | 0,1090 | 0,0471 | | | 0,0424 | 0,0397 | 0,0346 | 0,1567 | 0,0853 | | | 0,0674 |

*Table 37: Model results scenario 1 (Sittard)*

Scenario 2: Changing the order of OR blocks per day

| Variable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | SUM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X 1,1,d | 12 | 0 | 0 | 0 | 0 | | | 10 | 3 | 6 | 0 | 1 | | | 32 |
| X 2,1,d | 0 | 0 | 5 | 0 | 6 | | | 0 | 1 | 0 | 0 | 0 | | | 12 |
| X 3,1,d | 0 | 0 | 0 | 0 | 0 | | | 0 | 0 | 0 | 0 | 6 | | | 6 |
| X 4,1,d | 0 | 8 | 0 | 0 | 0 | | | 1 | 0 | 0 | 2 | 0 | | | 11 |
| | | | | | | | | | | | | | | | |
| X1,2,d | 0 | 0 | 1 | 7 | 1 | | | 0 | 1 | 1 | 2 | 2 | | | 15 |
| X2,2,d | 0 | 0 | 0 | 0 | 0 | | | 0 | 0 | 1 | 0 | 0 | | | 1 |
| X3,2,d | 1 | 0 | 0 | 2 | 0 | | | 0 | 0 | 1 | 0 | 0 | | | 4 |
| X4,2,d | 0 | 0 | 6 | 2 | 0 | | | 5 | 0 | 0 | 9 | 0 | | | 22 |
| | | | | | | | | | | | | | | | |
| δ- ic,d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| δ- nu,d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| δ- dc,d | 0 | 0 | 0 | 0 | 0 | | | 0 | 0 | 0 | 0 | 0 | | | 0 |
| | | | | | | | | | | | | | | | |
| δ+ ic,d | -10 | -10 | -8 | -9 | -7 | -9 | -11 | -11 | -10 | -10 | -11 | -11 | -11 | -11 | |
| δ+ nu,d | -3 | 0 | -3 | -6 | -6 | -8 | -11 | -2 | -2 | -1 | -2 | 0 | -7 | -11 | |
| δ+ dc,d | -48 | -49 | -46 | -42 | -48 | | | -46 | -49 | -48 | -43 | -47 | | | |
| SUM surplus | 1830 | 1770 | 1710 | 1710 | 1830 | 510 | 660 | 1770 | 1830 | 1770 | 1680 | 1740 | 540 | 660 | 20010 |
| | | | | | | | | | | | | | | | |
| δ+ nu hz,d | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| SUM wrong hz | 0 | 140 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 140 |
| | | | | | | | | | | | | | | | |
| Oc,s*Xc,s,d + Oc,1*qc,d*βc,d (required) | 31,4080 | 11,6266 | 19,5140 | 15,7359 | 15,7575 | | | 31,7100 | 11,7497 | 19,2206 | 15,7847 | 15,5356 | | | |
| | | | | | | | | | | | | | | | |
| C orblock,d * L orblock (max available capacity) | 32 | 12 | 20 | 16 | 16 | | | 32 | 12 | 20 | 16 | 16 | | | |
| OR occupancy | 0,9815 | 0,9689 | 0,9757 | 0,9835 | 0,9848 | | | 0,9909 | 0,9791 | 0,9610 | 0,9865 | 0,9710 | | | 0,9783 |
| | | | | | | | | | | | | | | | |
| Expected number of beds ic | 1,6682 | 1,5660 | 4,4482 | 2,6042 | 5,0706 | 2,6327 | 0,7494 | 1,3964 | 1,9001 | 1,7280 | 1,1761 | 1,1607 | 0,7721 | 0,7134 | |
| Patients hospitalized during current cycle at IC | 1,1049 | 1,0951 | 4,0133 | 2,2274 | 4,7455 | 2,4583 | 0,6354 | 1,3611 | 1,8744 | 1,7201 | 1,1713 | 1,1607 | 0,7721 | 0,7134 | |
| Patients hospitalized in earlier cycles at IC | 0,5633 | 0,4710 | 0,4349 | 0,3768 | 0,3251 | 0,1744 | 0,1140 | 0,0353 | 0,0257 | 0,0079 | 0,0048 | | | | |
| | | | | | | | | | | | | | | | |
| C ic,d*R ic,d (max available capacity) | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | |
| | | | | | | | | | | | | | | | |
| Bed occupancy IC | 0,1390 | 0,1305 | 0,3707 | 0,2170 | 0,4226 | 0,2194 | 0,0624 | 0,1164 | 0,1583 | 0,1440 | 0,0980 | 0,0967 | 0,0643 | 0,0594 | 0,1642 |
| | | | | | | | | | | | | | | | |
| Expected number of beds nu | 40,1191 | 44,8491 | 39,7712 | 37,3296 | 37,0675 | 34,5618 | 32,3100 | 41,2255 | 40,5981 | 42,2410 | 40,9532 | 42,6668 | 36,0895 | 31,7719 | |
| Patients hospitalized during current cycle at NU | 15,7219 | 24,9272 | 23,4196 | 23,8019 | 25,9525 | 25,2522 | 24,5513 | 34,6736 | 35,1925 | 37,8327 | 37,4360 | 39,9529 | 33,9130 | 30,0491 | |
| Patients hospitalized in earlier cycles at NU | 24,3972 | 19,9219 | 16,3517 | 13,5277 | 11,1150 | 9,3096 | 7,7587 | 6,5519 | 5,4057 | 4,4084 | 3,5172 | 2,7139 | 2,1766 | 1,7228 | |
| | | | | | | | | | | | | | | | |
| C nu,d,hz * R nu,d (max available capacity) | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | |
| | | | | | | | | | | | | | | | |
| Bed occupancy NU | 0,8915 | 0,9966 | 0,8838 | 0,8295 | 0,8237 | 0,7680 | 0,7180 | 0,9161 | 0,9022 | 0,9387 | 0,9101 | 0,9482 | 0,8020 | 0,7060 | 0,8596 |
| | | | | | | | | | | | | | | | |
| Expected number of hours dc | 19,8496 | 6,0376 | 52,6073 | 93,9013 | 28,2346 | | | 44,3273 | 14,9147 | 27,8108 | 79,5679 | 37,1117 | | | |
| Expected number of beds dc | 1,6541 | 0,5031 | 4,3839 | 7,8251 | 2,3529 | | | 3,6939 | 1,2429 | 2,3176 | 6,6307 | 3,0926 | | | |
| C dc,d * R dc,d (max available capacity) | 600 | 600 | 600 | 600 | 600 | | | 600 | 600 | 600 | 600 | 600 | | | |
| | | | | | | | | | | | | | | | |
| Bed occupancy DC | 0,0331 | 0,0101 | 0,0877 | 0,1565 | 0,0471 | | | 0,0739 | 0,0249 | 0,0464 | 0,1326 | 0,0619 | | | 0,0674 |

*Table 38: Model results scenario 2 (Sittard)*

Scenario 3: Changing the allowed number of wrong hospitalizations without creating bed deficit

| Variable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | SUM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X 1,1,d | 9 | 0 | 1 | 0 | 0 | | | 11 | 4 | 5 | 1 | 1 | | | 32 |
| X 2,1,d | 0 | 0 | 6 | 0 | 6 | | | 0 | 0 | 0 | 0 | 0 | | | 12 |
| X 3,1,d | 0 | 0 | 0 | 0 | 0 | | | 1 | 0 | 0 | 0 | 5 | | | 6 |
| X 4,1,d | 0 | 8 | 0 | 0 | 0 | | | 0 | 0 | 0 | 3 | 0 | | | 11 |
| | | | | | | | | | | | | | | | |
| X1,2,d | 4 | 0 | 0 | 3 | 1 | | | 0 | 0 | 4 | 0 | 3 | | | 15 |
| X2,2,d | 0 | 0 | 0 | 1 | 0 | | | 0 | 0 | 0 | 0 | 0 | | | 1 |
| X3,2,d | 0 | 0 | 0 | 0 | 0 | | | 1 | 0 | 0 | 3 | 0 | | | 4 |
| X4,2,d | 3 | 0 | 3 | 9 | 0 | | | 1 | 1 | 1 | 4 | 0 | | | 22 |
| | | | | | | | | | | | | | | | |
| δ- ic,d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| δ- nu,d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| δ- dc,d | 0 | 0 | 0 | 0 | 0 | | | 0 | 0 | 0 | 0 | 0 | | | 0 |
| | | | | | | | | | | | | | | | |
| δ+ ic,d | -11 | -11 | -7 | -9 | -7 | -9 | -11 | -11 | -11 | -11 | -11 | -11 | -11 | -11 | |
| δ+ nu,d | -5 | -1 | -4 | -6 | -6 | -8 | -10 | -1 | -1 | -1 | -1 | 0 | -7 | -11 | |
| δ+ dc,d | -44 | -49 | -48 | -42 | -48 | | | -48 | -49 | -46 | -46 | -46 | | | |
| SUM surplus | 1800 | 1830 | 1770 | 1710 | 1830 | 510 | 630 | 1800 | 1830 | 1740 | 1740 | 1710 | 540 | 660 | 20100 |
| | | | | | | | | | | | | | | | |
| δ+ nu hz,d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| SUM wrong hz | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oc,s*Xc,s,d + Oc,1*qc,d*βc,d (required) | 31,5697 | 11,6266 | 19,6210 | 15,6154 | 15,7575 | | | 31,5645 | 11,5615 | 19,6264 | 15,6803 | 15,4197 | | | |
| | | | | | | | | | | | | | | | |
| C orblock,d * L orblock (max available capacity) | 32 | 12 | 20 | 16 | 16 | | | 32 | 12 | 20 | 16 | 16 | | | |
| OR occupancy | 0,9866 | 0,9689 | 0,9811 | 0,9760 | 0,9848 | | | 0,9864 | 0,9635 | 0,9813 | 0,9800 | 0,9637 | | | 0,9772 |
| | | | | | | | | | | | | | | | |
| Expected number of beds ic | 1,4639 | 1,4691 | 5,1449 | 2,9300 | 5,0816 | 2,6115 | 0,7176 | 1,4289 | 1,3169 | 1,3534 | 1,2533 | 1,2018 | 0,8400 | 0,7733 | |
| Patients hospitalized during current cycle at IC | 0,8532 | 0,9556 | 4,6722 | 2,5163 | 4,7289 | 2,4198 | 0,6014 | 1,3823 | 1,2912 | 1,3455 | 1,2485 | 1,2018 | 0,8400 | 0,7733 | |
| Patients hospitalized in earlier cycles at IC | 0,6108 | 0,5135 | 0,4727 | 0,4137 | 0,3527 | 0,1917 | 0,1162 | 0,0467 | 0,0257 | 0,0079 | 0,0048 | | | | |
| | | | | | | | | | | | | | | | |
| C ic,d*R ic,d (max available capacity) | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | |
| | | | | | | | | | | | | | | | |
| Bed occupancy IC | 0,1220 | 0,1224 | 0,4287 | 0,2442 | 0,4235 | 0,2176 | 0,0598 | 0,1191 | 0,1097 | 0,1128 | 0,1044 | 0,1001 | 0,0700 | 0,0644 | 0,1642 |
| | | | | | | | | | | | | | | | |
| Expected number of beds nu | 37,5385 | 42,4064 | 39,2592 | 37,2762 | 37,1976 | 34,8753 | 32,6207 | 42,4531 | 42,2592 | 42,4036 | 42,4967 | 42,9918 | 36,3005 | 31,9276 | |
| Patients hospitalized during current cycle at NU | 12,9736 | 22,3660 | 22,8388 | 23,6840 | 26,0180 | 25,4449 | 24,7746 | 35,8517 | 36,8316 | 38,0132 | 39,0187 | 40,3119 | 34,1744 | 30,2441 | |
| Patients hospitalized in earlier cycles at NU | 24,5649 | 20,0404 | 16,4203 | 13,5922 | 11,1795 | 9,4304 | 7,8461 | 6,6013 | 5,4277 | 4,3905 | 3,4780 | 2,6800 | 2,1261 | 1,6835 | |
| | | | | | | | | | | | | | | | |
| C nu,d,hz * R nu,d (max available capacity) | 43 | 43 | 43 | 43 | 43 | 43 | 43 | 43 | 43 | 43 | 43 | 43 | 43 | 43 | |
| | | | | | | | | | | | | | | | |
| Bed occupancy NU | 0,8730 | 0,9862 | 0,9130 | 0,8669 | 0,8651 | 0,8111 | 0,7586 | 0,9873 | 0,9828 | 0,9861 | 0,9883 | 0,9998 | 0,8442 | 0,7425 | 0,9003 |
| | | | | | | | | | | | | | | | |
| Expected number of hours dc | 67,2335 | 6,0376 | 24,8269 | 94,4273 | 28,2346 | | | 26,1507 | 12,3387 | 47,7331 | 51,3916 | 45,9888 | | | |
| Expected number of beds dc | 5,6028 | 0,5031 | 2,0689 | 7,8689 | 2,3529 | | | 2,1792 | 1,0282 | 3,9778 | 4,2826 | 3,8324 | | | |
| C dc,d * R dc,d (max available capacity) | 600 | 600 | 600 | 600 | 600 | | | 600 | 600 | 600 | 600 | 600 | | | |
| | | | | | | | | | | | | | | | |
| Bed occupancy DC | 0,1121 | 0,0101 | 0,0414 | 0,1574 | 0,0471 | | | 0,0436 | 0,0206 | 0,0796 | 0,0857 | 0,0766 | | | 0,0674 |

*Table 39: Model results scenario 3 (Sittard)*

Scenario 4: Changing the maximum bed capacity at the nursing unit

| Variable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | SUM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $X_{1,1,d}$ | 12 | 3 | 2 | 1 | 0 | | | 4 | 4 | 5 | 0 | 1 | | | 32 |
| $X_{2,1,d}$ | 0 | 1 | 5 | 0 | 6 | | | 0 | 0 | 0 | 0 | 0 | | | 12 |
| $X_{3,1,d}$ | 0 | 0 | 0 | 0 | 1 | | | 0 | 0 | 0 | 0 | 5 | | | 6 |
| $X_{4,1,d}$ | 0 | 1 | 1 | 1 | 0 | | | 4 | 0 | 0 | 4 | 0 | | | 11 |
| $X_{1,2,d}$ | 1 | 0 | 1 | 7 | 0 | | | 0 | 0 | 1 | 3 | 2 | | | 15 |
| $X_{2,2,d}$ | 0 | 0 | 0 | 1 | 0 | | | 0 | 0 | 0 | 0 | 0 | | | 1 |
| $X_{3,2,d}$ | 0 | 0 | 0 | 0 | 0 | | | 0 | 0 | 0 | 3 | 1 | | | 4 |
| $X_{4,2,d}$ | 0 | 0 | 0 | 0 | 0 | | | 15 | 1 | 5 | 1 | 0 | | | 22 |
| $\delta^-_{ic,d}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| $\delta^-_{nu,d}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| $\delta^-_{dc,d}$ | 0 | 0 | 0 | 0 | 0 | | | 0 | 0 | 0 | 0 | 0 | | | 0 |
| $\delta^+_{ic,d}$ | -10 | -10 | -7 | -9 | -7 | -9 | -11 | -11 | -11 | -11 | -11 | -11 | -11 | -11 | |
| $\delta^+_{nu,d}$ | -1 | 0 | 0 | 0 | 0 | -4 | -6 | -1 | -2 | -1 | -1 | 0 | -6 | -10 | |
| $\delta^+_{dc,d}$ | -48 | -49 | -49 | -44 | -48 | | | -41 | -49 | -46 | -45 | -46 | | | |
| SUM surplus | 1770 | 1770 | 1680 | 1590 | 1650 | 390 | 510 | 1590 | 1860 | 1740 | 1710 | 1710 | 510 | 630 | 19110 |
| $\delta^+_{nu\,hz,d}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| SUM wrong hz | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $O_{c,s}*X_{c,s,d}+O_{c,1}*q_{c,d}*\beta_{c,d}$ (required) | 31,4479 | 11,6717 | 19,4887 | 15,7646 | 15,8734 | | | 31,5857 | 11,5615 | 19,4925 | 15,7768 | 15,3798 | | | |
| $C_{orblock,d}*L_{orblock}$ (max available capacity) | 32 | 12 | 20 | 16 | 16 | | | 32 | 12 | 20 | 16 | 16 | | | |
| OR occupancy | 0,9827 | 0,9726 | 0,9744 | 0,9853 | 0,9921 | | | 0,9871 | 0,9635 | 0,9746 | 0,9860 | 0,9612 | | | 0,9780 |
| Expected number of beds ic | 1,6097 | 2,0585 | 4,8776 | 2,7695 | 5,1401 | 2,7368 | 0,8554 | 1,1492 | 1,2025 | 1,3461 | 1,2144 | 1,1774 | 0,7759 | 0,6733 | |
| Patients hospitalized during current cycle at IC | 1,1049 | 1,6675 | 4,5277 | 2,4640 | 4,8812 | 2,5595 | 0,7528 | 1,1139 | 1,1768 | 1,3382 | 1,2096 | 1,1774 | 0,7759 | 0,6733 | |
| Patients hospitalized in earlier cycles at IC | 0,5048 | 0,3910 | 0,3498 | 0,3055 | 0,2589 | 0,1773 | 0,1026 | 0,0353 | 0,0257 | 0,0079 | 0,0048 | | | | |
| $C_{ic,d}*R_{ic,d}$ (max available capacity) | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | |
| Bed occupancy IC | 0,1341 | 0,1715 | 0,4065 | 0,2308 | 0,4283 | 0,2281 | 0,0713 | 0,0958 | 0,1002 | 0,1122 | 0,1012 | 0,0981 | 0,0647 | 0,0561 | 0,1642 |
| Expected number of beds nu | 39,5949 | 40,9418 | 40,9881 | 40,9211 | 40,7784 | 37,1771 | 34,5290 | 40,4469 | 39,2782 | 40,1645 | 40,4858 | 40,9812 | 34,8478 | 30,9285 | |
| Patients hospitalized during current cycle at NU | 15,7219 | 21,3548 | 25,0012 | 27,7640 | 30,0583 | 28,4056 | 27,2455 | 34,3638 | 34,3451 | 36,0999 | 37,2344 | 38,4493 | 32,8090 | 29,3602 | |
| Patients hospitalized in earlier cycles at NU | 23,8730 | 19,5870 | 15,9868 | 13,1571 | 10,7201 | 8,7715 | 7,2835 | 6,0831 | 4,9332 | 4,0645 | 3,2514 | 2,5319 | 2,0388 | 1,5683 | |
| $C_{nu,d,hz}*R_{nu,d}$ (max available capacity) | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | |
| Bed occupancy NU | 0,9657 | 0,9986 | 0,9997 | 0,9981 | 0,9946 | 0,9068 | 0,8422 | 0,9865 | 0,9580 | 0,9796 | 0,9875 | 0,9995 | 0,8499 | 0,7544 | 0,9444 |
| Expected number of hours dc | 21,6989 | 6,0376 | 14,8007 | 73,2258 | 19,3575 | | | 107,3383 | 12,3387 | 46,3062 | 59,1196 | 44,1395 | | | |
| Expected number of beds dc | 1,8082 | 0,5031 | 1,2334 | 6,1021 | 1,6131 | | | 8,9449 | 1,0282 | 3,8589 | 4,9266 | 3,6783 | | | |
| $C_{dc,d}*R_{dc,d}$ (max available capacity) | 600 | 600 | 600 | 600 | 600 | | | 600 | 600 | 600 | 600 | 600 | | | |
| Bed occupancy DC | 0,0362 | 0,0101 | 0,0247 | 0,1220 | 0,0323 | | | 0,1789 | 0,0206 | 0,0772 | 0,0985 | 0,0736 | | | 0,0674 |

*Table 40: Model results scenario 4 (Sittard)*

Scenario 5: Changing the target percentage of occupied beds at the IC and DC

| Variable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | SUM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X 1,1,d | 10 | 0 | 2 | 2 | 4 | | | 7 | 3 | 4 | 0 | 0 | | | 32 |
| X 2,1,d | 2 | 1 | 2 | 1 | 2 | | | 1 | 0 | 1 | 0 | 2 | | | 12 |
| X 3,1,d | 0 | 0 | 0 | 0 | 0 | | | 2 | 0 | 0 | 0 | 4 | | | 6 |
| X 4,1,d | 0 | 4 | 2 | 0 | 0 | | | 1 | 0 | 0 | 4 | 0 | | | 11 |
| | | | | | | | | | | | | | | | |
| X1,2,d | 0 | 0 | 4 | 4 | 0 | | | 2 | 1 | 0 | 1 | 3 | | | 15 |
| X2,2,d | 0 | 0 | 0 | 0 | 0 | | | 0 | 1 | 0 | 0 | 0 | | | 1 |
| X3,2,d | 0 | 0 | 0 | 0 | 0 | | | 0 | 0 | 2 | 2 | 0 | | | 4 |
| X4,2,d | 2 | 3 | 1 | 2 | 0 | | | 4 | 1 | 4 | 5 | 0 | | | 22 |
| | | | | | | | | | | | | | | | |
| δ- ic,d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| δ- nu,d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| δ- dc,d | 0 | 0 | 0 | 0 | 0 | | | 0 | 0 | 0 | 0 | 0 | | | 0 |
| | | | | | | | | | | | | | | | |
| δ+ ic,d | 0 | 0 | 0 | -1 | 0 | -1 | -2 | -1 | -1 | -1 | -1 | -1 | -2 | -2 | |
| δ+ nu,d | -2 | 0 | 0 | -1 | 0 | -4 | -8 | 0 | -1 | -1 | 0 | 0 | -6 | -9 | |
| δ+ dc,d | -3 | -3 | -1 | -1 | -3 | | | 0 | -3 | -1 | 0 | -1 | | | |
| SUM surplus | 150 | 90 | 30 | 90 | 90 | 150 | 300 | 30 | 150 | 90 | 30 | 60 | 240 | 330 | 1830 |
| | | | | | | | | | | | | | | | |
| δ+ nu hz,d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| SUM wrong hz | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oc,s*Xc,s,d + Oc,1*qc,d*βc,d (required) | 31,6904 | 11,5595 | 19,4946 | 15,7482 | 15,1386 | | | 31,5595 | 11,6696 | 19,6009 | 15,6828 | 15,8985 | | | |
| | | | | | | | | | | | | | | | |
| C orblock,d * L orblock (max available capacity) | 32 | 12 | 20 | 16 | 16 | | | 32 | 12 | 20 | 16 | 16 | | | |
| OR occupancy | 0,9903 | 0,9633 | 0,9747 | 0,9843 | 0,9462 | | | 0,9862 | 0,9725 | 0,9800 | 0,9802 | 0,9937 | | | 0,9771 |
| | | | | | | | | | | | | | | | |
| Expected number of beds ic | 2,8067 | 2,5293 | 2,8446 | 2,4304 | 2,9941 | 1,5700 | 0,7821 | 1,9864 | 1,5486 | 1,9767 | 1,5130 | 2,4301 | 1,4058 | 0,7685 | |
| Patients hospitalized during current cycle at IC | 2,2641 | 2,1109 | 2,5082 | 2,1374 | 2,7500 | 1,4347 | 0,7078 | 1,9647 | 1,5342 | 1,9688 | 1,5082 | 2,4301 | 1,4058 | 0,7685 | |
| Patients hospitalized in earlier cycles at IC | 0,5426 | 0,4184 | 0,3364 | 0,2930 | 0,2441 | 0,1353 | 0,0743 | 0,0217 | 0,0143 | 0,0079 | 0,0048 | | | | |
| | | | | | | | | | | | | | | | |
| C ic,d*R ic,d (max available capacity) | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | |
| | | | | | | | | | | | | | | | |
| Bed occupancy IC | 0,9356 | 0,8431 | 0,9482 | 0,8101 | 0,9980 | 0,5233 | 0,2607 | 0,6621 | 0,5162 | 0,6589 | 0,5043 | 0,8100 | 0,4686 | 0,2562 | 0,6568 |
| | | | | | | | | | | | | | | | |
| Expected number of beds nu | 38,8722 | 40,8002 | 40,8624 | 39,9838 | 40,9689 | 36,9167 | 32,8770 | 40,9751 | 39,6707 | 40,0753 | 40,8868 | 40,5561 | 35,0586 | 31,5358 | |
| Patients hospitalized during current cycle at NU | 14,5627 | 20,9585 | 24,5924 | 26,6149 | 29,9754 | 27,7687 | 25,2674 | 34,6430 | 34,4777 | 35,8509 | 37,4739 | 37,9060 | 32,9846 | 29,9695 | |
| Patients hospitalized in earlier cycles at NU | 24,3095 | 19,8417 | 16,2701 | 13,3689 | 10,9935 | 9,1480 | 7,6096 | 6,3321 | 5,1930 | 4,2245 | 3,4129 | 2,6501 | 2,0740 | 1,5664 | |
| | | | | | | | | | | | | | | | |
| C nu,d,hz * R nu,d (max available capacity) | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | |
| | | | | | | | | | | | | | | | |
| Bed occupancy NU | 0,9481 | 0,9951 | 0,9966 | 0,9752 | 0,9992 | 0,9004 | 0,8019 | 0,9994 | 0,9676 | 0,9774 | 0,9972 | 0,9892 | 0,8551 | 0,7692 | 0,9408 |
| | | | | | | | | | | | | | | | |
| Expected number of hours dc | 25,4240 | 24,9409 | 47,7331 | 53,2144 | 19,3575 | | | 55,7804 | 27,1981 | 45,1836 | 59,5420 | 45,9888 | | | |
| Expected number of beds dc | 2,1187 | 2,0784 | 3,9778 | 4,4345 | 1,6131 | | | 4,6484 | 2,2665 | 3,7653 | 4,9618 | 3,8324 | | | |
| C dc,d * R dc,d (max available capacity) | 60 | 60 | 60 | 60 | 60 | | | 60 | 60 | 60 | 60 | 60 | | | |
| | | | | | | | | | | | | | | | |
| Bed occupancy DC | 0,4237 | 0,4157 | 0,7956 | 0,8869 | 0,3226 | | | 0,9297 | 0,4533 | 0,7531 | 0,9924 | 0,7665 | | | 0,6739 |

*Table 41: Model results scenario 5 (Sittard)*

## D. Model results Heerlen

This appendix shows the results of the model testing and the scenario analysis for the situation in Heerlen. The first table in every scenario shows the solver solution with the lowest objective function value. The solver solution contains a division of the elective patients in the OR schedule within the planning horizon of 2 weeks (green). The first table also shows the consequences of the OR schedule on the bed occupancy (bed deficit, bed surplus and number of wrong hospitalizations). The second table shows the OR occupancy and the bed occupancy at the IC, NU and DC. Beneath examples are given of the calculation of the OR occupancy and the bed occupancy at the IC, NU and DC. The numbers in the examples are used from Table 42. The explanation apply to all tables following in this appendix.

- Calculation OR occupancy

OR occupancy = required capacity / max available OR capacity

OR occupancy = 32,0299 / 40,5

OR occupancy = 0,7909

- Calculation bed occupancy IC

Bed occupancy IC = expected number of beds IC / max available bed capacity IC

Bed occupancy IC = 6,2963 / 21

Bed occupancy IC = 0,2998

- Calculation bed occupancy NU

Bed occupancy NU = expected number of beds NU/ max available bed capacity NU

Bed occupancy NU = 72,4789 / 66

Bed occupancy NU = 1,0982

- Calculation bed occupancy DC

Bed occupancy DC = expected number of hours DC / max available hours DC

Bed occupancy DC = 38,3650 / 980

Bed occupancy DC = 0,0391

The values used for the OR occupancy and the bed occupancy at the IC, NU and DC in the main text are based on average values and can be found in every second table in the last column.

Testing phase

| Variable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | SUM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X 1,1,d | 0 | 4,952893283 | 14,03570158 | 0,081083229 | 6,179496048 | | | 15,9060206 | 6,924441913 | 3,939634871 | 0 | 4,980728474 | | | 57 |
| X 2,1,d | 4,011729891 | 0,065342377 | 0,145077611 | 2,192327806 | 1,246588304 | | | 0 | 0 | 3,981456417 | 5,028294712 | 0,329182881 | | | 17 |
| X 3,1,d | 1,41060669 | 2,049794657 | 0,115910837 | 0,17055584 | 0,244860497 | | | 0 | 0,956899985 | 0,985319811 | 2,020443469 | 0,045608215 | | | 8 |
| X 4,1,d | 12,66977274 | 0,019309223 | 0,050460048 | 0,090418091 | 0,165911229 | | | 0 | 0 | 0 | 0 | 0,004128664 | | | 13 |
| | | | | | | | | | | | | | | | |
| X1,2,d | 0 | 0 | 0 | 9 | 3 | | | 0 | 0 | 2 | 1 | 0 | | | 15 |
| X2,2,d | 0 | 0 | 0 | 0 | 0 | | | 0 | 0 | 1 | 1 | 0 | | | 2 |
| X3,2,d | 0 | 3 | 0 | 1 | 2 | | | 0 | 0 | 0 | 0 | 3 | | | 9 |
| X4,2,d | 4 | 8 | 0 | 0 | 0 | | | 0 | 10 | 8 | 0 | 8 | | | 38 |
| | | | | | | | | | | | | | | | |
| δ- ic,d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| δ- nu,d | 6 | 7 | 5 | 8 | 9 | 0 | 0 | 5 | 8 | 8 | 8 | 8 | 0 | 0 | |
| δ- dc,d | 0 | 0 | 0 | 0 | 0 | | | 0 | 0 | 0 | 0 | 0 | | | 72 |
| | | | | | | | | | | | | | | | |
| δ+ ic,d | -15 | -14 | -13 | -14 | -14 | -15 | -16 | -14 | -14 | -14 | -13 | -14 | -15 | -16 | |
| δ+ nu,d | 0 | 0 | 0 | 0 | 0 | 0 | -5 | 0 | 0 | 0 | 0 | 0 | 0 | -5 | 0,7143 |
| δ+ dc,d | -67 | -64 | -69 | -63 | -66 | | | -69 | -64 | -63 | -68 | -63 | | | |
| SUM surplus | 2460 | 2340 | 2460 | 2310 | 2400 | 450 | 630 | 2490 | 2340 | 2310 | 2430 | 2310 | 450 | 630 | 26010 |
| | | | | | | | | | | | | | | | |
| δ+ nu hz,d | 10 | 11 | 9 | 12 | 13 | 4 | 0 | 9 | 12 | 12 | 12 | 12 | 4 | 0 | |
| SUM wrong hz | 700 | 770 | 630 | 840 | 910 | 280 | 0 | 630 | 840 | 840 | 840 | 840 | 280 | 0 | 8400 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Required | 32,0299 | 26,1686 | 31,8603 | 18,7658 | 23,9077 | | | 35,3988 | 26,1201 | 30,8774 | 18,0836 | 23,0770 | | | |
| | | | | | | | | | | | | | | | |
| C orblock,d * L orblock (max available capacity) | 40,5 | 36 | 36 | 36 | 36 | | | 40,5 | 36 | 36 | 36 | 36 | | | |
| OR occupancy | 0,7909 | 0,7269 | 0,8850 | 0,5213 | 0,6641 | | | 0,8740 | 0,7256 | 0,8577 | 0,5023 | 0,6410 | | | 0,7189 |
| | | | | | | | | | | | | | | | |
| Expected number of beds ic | 6,2963 | 6,7006 | 7,8920 | 7,3861 | 7,2353 | 6,3063 | 5,2401 | 6,7156 | 7,2702 | 7,4802 | 7,5675 | 7,1573 | 6,0563 | 5,0806 | |
| Patients hospitalized during current cycle at IC | 1,9650 | 2,8996 | 4,4752 | 4,4131 | 4,9139 | 4,2017 | 3,5779 | 5,3340 | 6,0047 | 6,7553 | 7,1192 | 6,8814 | 5,8233 | 5,0301 | |
| Patients hospitalized in earlier cycles at IC | 4,3313 | 3,8010 | 3,4167 | 2,9730 | 2,3215 | 2,1046 | 1,6622 | 1,3816 | 1,2655 | 0,7249 | 0,4483 | 0,2760 | 0,2330 | 0,0505 | |
| | | | | | | | | | | | | | | | |
| C ic,d*R ic,d (max available capacity) | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | |
| | | | | | | | | | | | | | | | |
| Bed occupancy IC | 0,2998 | 0,3191 | 0,3758 | 0,3517 | 0,3445 | 0,3003 | 0,2495 | 0,3198 | 0,3462 | 0,3562 | 0,3604 | 0,3408 | 0,2884 | 0,2419 | 0,3210 |
| | | | | | | | | | | | | | | | |
| Expected number of beds nu | 72,4789 | 72,8332 | 70,5668 | 73,8907 | 74,6866 | 65,6763 | 56,6538 | 70,5546 | 74,1479 | 73,9509 | 73,7887 | 74,2768 | 66,0000 | 57,4452 | |
| Patients hospitalized during current cycle at NU | 29,6848 | 40,5502 | 45,3923 | 54,5304 | 59,8325 | 54,2650 | 47,7933 | 63,4423 | 68,7071 | 70,1056 | 71,0715 | 72,3063 | 64,5135 | 56,4146 | |
| Patients hospitalized in earlier cycles at NU | 42,7941 | 32,2830 | 25,1746 | 19,3603 | 14,8540 | 11,4113 | 8,8605 | 7,1123 | 5,4408 | 3,8452 | 2,7171 | 1,9705 | 1,4865 | 1,0307 | |
| | | | | | | | | | | | | | | | |
| C nu,d,hz * R nu,d (max available capacity) | 66 | 66 | 66 | 66 | 66 | 66 | 66 | 66 | 66 | 66 | 66 | 66 | 66 | 66 | |
| | | | | | | | | | | | | | | | |
| Bed occupancy NU | 1,0982 | 1,1035 | 1,0692 | 1,1196 | 1,1316 | 0,9951 | 0,8584 | 1,0690 | 1,1235 | 1,1205 | 1,1180 | 1,1254 | 1,0000 | 0,8704 | 1,0573 |
| | | | | | | | | | | | | | | | |
| Expected number of hours dc | 38,3650 | 90,9963 | 8,2770 | 92,5861 | 50,2133 | | | 8,8162 | 81,9282 | 92,3283 | 26,8653 | 92,4403 | | | |
| Expected number of beds dc | 2,7404 | 6,4997 | 0,5912 | 6,6133 | 3,5867 | | | 0,6297 | 5,8520 | 6,5949 | 1,9189 | 6,6029 | | | |
| C dc,d * R dc,d (max available capacity) | 980 | 980 | 980 | 980 | 980 | | | 980 | 980 | 980 | 980 | 980 | | | |
| | | | | | | | | | | | | | | | |
| Bed occupancy DC | 0,0391 | 0,0929 | 0,0084 | 0,0945 | 0,0512 | | | 0,0090 | 0,0836 | 0,0942 | 0,0274 | 0,0943 | | | 0,0595 |

*Table 42: Model testing results (Heerlen)*

## Scenario 1: Changing the maximum bed capacity at the nursing unit

| Variable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | SUM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X 1,1,d | 0 | 10 | 16 | 0 | 0 | | | 18 | 0 | 13 | 0 | 0 | | | 57 |
| X 2,1,d | 17 | 0 | 0 | 0 | 0 | | | 0 | 0 | 0 | 0 | 0 | | | 17 |
| X 3,1,d | 0 | 5 | 0 | 0 | 0 | | | 0 | 0 | 0 | 3 | 0 | | | 8 |
| X 4,1,d | 0 | 0 | 0 | 0 | 0 | | | 0 | 13 | 0 | 0 | 0 | | | 13 |
| | | | | | | | | | | | | | | | |
| X1,2,d | 0 | 0 | 0 | 10 | 0 | | | 0 | 0 | 5 | 0 | 0 | | | 15 |
| X2,2,d | 0 | 0 | 0 | 2 | 0 | | | 0 | 0 | 0 | 0 | 0 | | | 2 |
| X3,2,d | 0 | 0 | 0 | 0 | 1 | | | 0 | 8 | 0 | 0 | 0 | | | 9 |
| X4,2,d | 0 | 0 | 0 | 0 | 38 | | | 0 | 0 | 0 | 0 | 0 | | | 38 |
| | | | | | | | | | | | | | | | |
| δ- ic,d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| δ- nu,d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| δ- dc,d | 0 | 0 | 0 | 0 | 0 | | | 0 | 0 | 0 | 0 | 0 | | | 0 |
| | | | | | | | | | | | | | | | |
| δ+ ic,d | -13 | -12 | -11 | -13 | -15 | -16 | -16 | -14 | -14 | -13 | -14 | -15 | -16 | -17 | |
| δ+ nu,d | -13 | 0 | 0 | 0 | -8 | -18 | -26 | -10 | -1 | -1 | -6 | -12 | -19 | -26 | |
| δ+ dc,d | -69 | -69 | -69 | -62 | -49 | | | -69 | -65 | -66 | -69 | -69 | | | |
| SUM surplus | 2850 | 2430 | 2400 | 2250 | 2160 | 1020 | 1260 | 2790 | 2400 | 2400 | 2670 | 2880 | 1050 | 1290 | 29850 |
| | | | | | | | | | | | | | | | |
| δ+ nu hz,d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| SUM wrong hz | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Required | 40,0061 | 31,6225 | 35,608 | 15,2936 | 35,2157 | | | 40,059 | 27,4552 | 35,4085 | 5,6205 | 0 | | | |
| | | | | | | | | | | | | | | | |
| C orblock,d * L orblock (max available capacity) | 40,5 | 36 | 36 | 36 | 36 | | | 40,5 | 36 | 36 | 36 | 36 | | | |
| OR occupancy | 0,9878 | 0,8784 | 0,9891 | 0,4248 | 0,9782 | | | 0,9891 | 0,7626 | 0,9836 | 0,1561 | 0,0000 | | | 0,7150 |
| | | | | | | | | | | | | | | | |
| Expected number of beds ic | 8,0831 | 8,9141 | 9,6044 | 7,7311 | 6,3035 | 5,4872 | 4,9173 | 6,8700 | 7,1706 | 7,5433 | 6,9868 | 5,5040 | 4,8548 | 4,4142 | |
| Patients hospitalized during current cycle at IC | 4,2306 | 5,4318 | 6,4494 | 5,1324 | 4,4764 | 3,8368 | 3,4414 | 5,5342 | 5,9369 | 6,9138 | 6,4295 | 5,3711 | 4,7615 | 4,3637 | |
| Patients hospitalized in earlier cycles at IC | 3,8525 | 3,4823 | 3,1549 | 2,5988 | 1,8272 | 1,6504 | 1,4759 | 1,3358 | 1,2337 | 0,6295 | 0,5573 | 0,1329 | 0,0932 | 0,0505 | |
| | | | | | | | | | | | | | | | |
| C ic,d*R ic,d (max available capacity) | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | |
| | | | | | | | | | | | | | | | |
| Bed occupancy IC | 0,3849 | 0,4245 | 0,4574 | 0,3681 | 0,3002 | 0,2613 | 0,2342 | 0,3271 | 0,3415 | 0,3592 | 0,3327 | 0,2621 | 0,2312 | 0,2102 | 0,3210 |
| | | | | | | | | | | | | | | | |
| Expected number of beds nu | 66,6840 | 79,6096 | 79,5457 | 79,5138 | 71,9576 | 61,7745 | 53,8125 | 69,7181 | 78,9000 | 78,8882 | 73,9960 | 68,4682 | 60,8429 | 53,7467 | |
| Patients hospitalized during current cycle at NU | 26,3271 | 49,3896 | 56,0094 | 61,3632 | 57,8760 | 52,1523 | 46,6413 | 64,2781 | 74,8148 | 76,1228 | 72,1475 | 67,4546 | 60,2261 | 53,4114 | |
| Patients hospitalized in earlier cycles at NU | 40,3569 | 30,2201 | 23,5363 | 18,1506 | 14,0815 | 9,6222 | 7,1712 | 5,4399 | 4,0852 | 2,7654 | 1,8485 | 1,0136 | 0,6169 | 0,3352 | |
| | | | | | | | | | | | | | | | |
| C nu,d,hz * R nu,d (max available capacity) | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | |
| | | | | | | | | | | | | | | | |
| Bed occupancy NU | 0,8335 | 0,9951 | 0,9943 | 0,9939 | 0,8995 | 0,7722 | 0,6727 | 0,8715 | 0,9862 | 0,9861 | 0,9249 | 0,8559 | 0,7605 | 0,6718 | 0,8727 |
| | | | | | | | | | | | | | | | |
| Expected number of hours dc | 8,8162 | 8,0562 | 8,2770 | 109,7279 | 298,1613 | | | 8,8162 | 71,6362 | 49,6405 | 10,1843 | 9,5002 | | | |
| Expected number of beds dc | 0,6297 | 0,5754 | 0,5912 | 7,8377 | 21,2972 | | | 0,6297 | 5,1169 | 3,5458 | 0,7274 | 0,6786 | | | |
| C dc,d * R dc,d (max available capacity) | 980 | 980 | 980 | 980 | 980 | | | 980 | 980 | 980 | 980 | 980 | | | |
| | | | | | | | | | | | | | | | |
| Bed occupancy DC | 0,0090 | 0,0082 | 0,0084 | 0,1120 | 0,3042 | | | 0,0090 | 0,0731 | 0,0507 | 0,0104 | 0,0097 | | | 0,0595 |

*Table 43: Model results scenario 1 (Heerlen)*

## Scenario 2: Changing the order of the OR blocks

| Variable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | SUM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X 1,1,d | 0 | 9 | 14 | 0 | 0 | | | 20 | 0 | 14 | 0 | 0 | | | 57 |
| X 2,1,d | 17 | 0 | 0 | 0 | 0 | | | 0 | 0 | 0 | 0 | 0 | | | 17 |
| X 3,1,d | 0 | 5 | 0 | 0 | 0 | | | 0 | 0 | 0 | 3 | 0 | | | 8 |
| X 4,1,d | 0 | 1 | 0 | 0 | 0 | | | 0 | 12 | 0 | 0 | 0 | | | 13 |
| | | | | | | | | | | | | | | | |
| X1,2,d | 2 | 0 | 0 | 13 | 0 | | | 0 | 0 | 0 | 0 | 0 | | | 15 |
| X2,2,d | 0 | 0 | 0 | 2 | 0 | | | 0 | 0 | 0 | 0 | 0 | | | 2 |
| X3,2,d | 1 | 0 | 0 | 0 | 8 | | | 0 | 0 | 0 | 0 | 0 | | | 9 |
| X4,2,d | 0 | 0 | 0 | 0 | 38 | | | 0 | 0 | 0 | 0 | 0 | | | 38 |
| | | | | | | | | | | | | | | | |
| δ- ic,d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| δ- nu,d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| δ- dc,d | 0 | 0 | 0 | 0 | 0 | | | 0 | 0 | 0 | 0 | 0 | | | 0 |
| | | | | | | | | | | | | | | | |
| δ+ ic,d | -13 | -12 | -12 | -13 | -15 | -16 | -16 | -14 | -14 | -13 | -14 | -15 | -16 | -17 | |
| δ+ nu,d | -13 | 0 | -2 | -2 | -9 | -19 | -27 | -9 | -1 | 0 | -5 | -11 | -19 | -26 | |
| δ+ dc,d | -68 | -69 | -69 | -60 | -45 | | | -69 | -69 | -69 | -69 | -69 | | | |
| SUM surplus | 2820 | 2430 | 2490 | 2250 | 2070 | 1050 | 1290 | 2760 | 2520 | 2460 | 2640 | 2850 | 1050 | 1290 | 29970 |
| | | | | | | | | | | | | | | | |
| δ+ nu hz,d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| SUM wrong hz | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Required | 43,928 | 30,6898 | 31,157 | 19,1798 | 44,5334 | | | 44,51 | 15,5136 | 31,157 | 5,6205 | 0 | | | |
| | | | | | | | | | | | | | | | |
| C orblock,d * L orblock (max available capacity) | 45 | 31,5 | 31,5 | 31,5 | 45 | | | 45 | 31,5 | 31,5 | 31,5 | 45 | | | |
| OR occupancy | 0,9762 | 0,9743 | 0,9891 | 0,6089 | 0,9896 | | | 0,9891 | 0,4925 | 0,9891 | 0,1784 | 0,0000 | | | 0,7187 |
| | | | | | | | | | | | | | | | |
| Expected number of beds ic | 8,0919 | 8,8463 | 9,3056 | 7,5156 | 6,2189 | 5,4343 | 4,8803 | 7,0992 | 7,3185 | 7,7047 | 7,1076 | 5,5507 | 4,8778 | 4,4331 | |
| Patients hospitalized during current cycle at IC | 4,2306 | 5,3546 | 6,1378 | 4,8790 | 4,2905 | 3,6851 | 3,3109 | 5,6739 | 5,9983 | 7,0465 | 6,5222 | 5,4177 | 4,7846 | 4,3826 | |
| Patients hospitalized in earlier cycles at IC | 3,8614 | 3,4917 | 3,1678 | 2,6367 | 1,9284 | 1,7492 | 1,5694 | 1,4253 | 1,3202 | 0,6582 | 0,5854 | 0,1329 | 0,0932 | 0,0505 | |
| | | | | | | | | | | | | | | | |
| C ic,d*R ic,d (max available capacity) | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | |
| | | | | | | | | | | | | | | | |
| Bed occupancy IC | 0,3853 | 0,4213 | 0,4431 | 0,3579 | 0,2961 | 0,2588 | 0,2324 | 0,3381 | 0,3485 | 0,3669 | 0,3385 | 0,2643 | 0,2323 | 0,2111 | 0,3210 |
| | | | | | | | | | | | | | | | |
| Expected number of beds nu | 66,9793 | 79,9331 | 77,8143 | 78,0516 | 71,0489 | 61,0702 | 53,2448 | 70,9929 | 79,0847 | 79,8225 | 74,9184 | 69,0797 | 61,3204 | 54,0967 | |
| Patients hospitalized during current cycle at NU | 26,3271 | 49,4669 | 54,0843 | 59,7183 | 56,7962 | 51,2654 | 45,9099 | 65,4126 | 74,8861 | 76,9922 | 73,0232 | 68,0504 | 60,6965 | 53,7598 | |
| Patients hospitalized in earlier cycles at NU | 40,6522 | 30,4662 | 23,7300 | 18,3333 | 14,2527 | 9,8049 | 7,3349 | 5,5803 | 4,1987 | 2,8303 | 1,8953 | 1,0294 | 0,6239 | 0,3370 | |
| | | | | | | | | | | | | | | | |
| C nu,d,hz * R nu,d (max available capacity) | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | |
| | | | | | | | | | | | | | | | |
| Bed occupancy NU | 0,8372 | 0,9992 | 0,9727 | 0,9756 | 0,8881 | 0,7634 | 0,6656 | 0,8874 | 0,9886 | 0,9978 | 0,9365 | 0,8635 | 0,7665 | 0,6762 | 0,8727 |
| | | | | | | | | | | | | | | | |
| Expected number of hours dc | 33,3091 | 8,0562 | 8,2770 | 134,5460 | 353,7938 | | | 8,8162 | 8,0562 | 8,2770 | 10,1843 | 9,5002 | | | |
| Expected number of beds dc | 2,3792 | 0,5754 | 0,5912 | 9,6104 | 25,2710 | | | 0,6297 | 0,5754 | 0,5912 | 0,7274 | 0,6786 | | | |
| C dc,d * R dc,d (max available capacity) | 980 | 980 | 980 | 980 | 980 | | | 980 | 980 | 980 | 980 | 980 | | | |
| | | | | | | | | | | | | | | | |
| Bed occupancy DC | 0,0340 | 0,0082 | 0,0084 | 0,1373 | 0,3610 | | | 0,0090 | 0,0082 | 0,0084 | 0,0104 | 0,0097 | | | 0,0595 |

*Table 44: Model results scenario 2 (Heerlen)*

**Scenario 3: Changing the maximum OR capacity**

It is important to check the relation between the maximum OR capacity and the OR capacity needed to treat all elective patients. The urgent patient flow is scheduled at the emergent operating room, available during the day. The time needed for the urgent patient flow arriving during the day is equal to $\sum_{c\in N}\sum_{s\in S} O_{c,s}q_{c,d}\beta_{c,d}$ = (2*(3,4860+3,9954+3,5234+3,4236+4,0579)) = 36,9724 < 90 (9*10) hours, so the urgent patient flow can be treated at the emergent operating room.

The OR capacity needed to treat all elective patients is equal to:

((57*2,2255)+(17*2,3533)+(8*1,8735)+(13*1,2928)+(15*1,2954)+(2*1,1698)+(9*1,3311)+(38*0,8917)) = 266,2891 hours in two weeks.

The maximum OR capacity available is equal to (41*4,5) = 184,5 hours per week so 369 hours in two weeks. The available OR capacity contains about 100 hours more than needed. This could also influence the results of the mathematical model.

So in phase 4 the maximum bed capacity at the nursing unit is still equal to 80; however the maximum OR capacity is decreased to 30 OR blocks (100/4.5 = 22 OR blocks/ 2 weeks → 11 OR blocks per week → 41-11 = 30 OR blocks) available per week.

## Scenario 3: Changing the maximum OR capacity

| Variable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | SUM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X 1,1,d | 0 | 2 | 10 | 0 | 0 | | | 16 | 6 | 9 | 0 | 14 | | | 57 |
| X 2,1,d | 15 | 0 | 0 | 2 | 0 | | | 0 | 0 | 0 | 0 | 0 | | | 17 |
| X 3,1,d | 0 | 6 | 0 | 2 | 0 | | | 0 | 0 | 0 | 0 | 0 | | | 8 |
| X 4,1,d | 0 | 5 | 0 | 0 | 0 | | | 0 | 7 | 1 | 0 | 0 | | | 13 |
| | | | | | | | | | | | | | | | |
| X1,2,d | 0 | 0 | 0 | 9 | 6 | | | 0 | 0 | 0 | 0 | 0 | | | 15 |
| X2,2,d | 0 | 0 | 0 | 2 | 0 | | | 0 | 0 | 0 | 0 | 0 | | | 2 |
| X3,2,d | 0 | 0 | 0 | 0 | 9 | | | 0 | 0 | 0 | 0 | 0 | | | 9 |
| X4,2,d | 0 | 0 | 0 | 0 | 13 | | | 0 | 0 | 0 | 25 | 0 | | | 38 |
| | | | | | | | | | | | | | | | |
| δ- ic,d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| δ- nu,d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| δ- dc,d | 0 | 0 | 0 | 0 | 0 | | | 0 | 0 | 0 | 0 | 0 | | | 0 |
| | | | | | | | | | | | | | | | |
| δ+ ic,d | -13 | -13 | -13 | -14 | -15 | -15 | -16 | -14 | -14 | -14 | -15 | -14 | -15 | -16 | |
| δ+ nu,d | -12 | 0 | -7 | -2 | -9 | -18 | -26 | -12 | -3 | -4 | -11 | -3 | -12 | -22 | |
| δ+ dc,d | -69 | -69 | -69 | -63 | -54 | | | -69 | -69 | -69 | -56 | -69 | | | |
| SUM surplus | 2820 | 2460 | 2670 | 2370 | 2340 | 990 | 1260 | 2850 | 2580 | 2610 | 2460 | 2580 | 810 | 1140 | 29940 |
| | | | | | | | | | | | | | | | |
| δ+ nu hz,d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| SUM wrong hz | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Required | 35,2995 | 22,156 | 22,255 | 22,4518 | 31,3444 | | | 35,608 | 22,4026 | 21,3223 | 22,2925 | 31,157 | | | |
| | | | | | | | | | | | | | | | |
| C orblock,d * L orblock (max available capacity) | 36 | 22,5 | 22,5 | 22,5 | 31,5 | | | 36 | 22,5 | 22,5 | 22,5 | 31,5 | | | |
| OR occupancy | 0,9805 | 0,9847 | 0,9891 | 0,9979 | 0,9951 | | | 0,9891 | 0,9957 | 0,9477 | 0,9908 | 0,9891 | | | 0,9860 |
| | | | | | | | | | | | | | | | |
| Expected number of beds ic | 7,9228 | 8,0546 | 8,1168 | 7,4108 | 6,3408 | 5,5294 | 4,9487 | 6,6854 | 7,4441 | 7,4121 | 6,4845 | 6,9646 | 6,1391 | 4,9307 | |
| Patients hospitalized during current cycle at IC | 3,7794 | 4,3493 | 4,8555 | 4,4844 | 3,9981 | 3,3926 | 2,9822 | 4,8964 | 5,7841 | 6,2982 | 5,6334 | 6,4305 | 5,6529 | 4,8802 | |
| Patients hospitalized in earlier cycles at IC | 4,1433 | 3,7053 | 3,2612 | 2,9264 | 2,3427 | 2,1368 | 1,9666 | 1,7891 | 1,6600 | 1,1139 | 0,8511 | 0,5341 | 0,4862 | 0,0505 | |
| | | | | | | | | | | | | | | | |
| C ic,d*R ic,d (max available capacity) | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | |
| | | | | | | | | | | | | | | | |
| Bed occupancy IC | 0,3773 | 0,3836 | 0,3865 | 0,3529 | 0,3019 | 0,2633 | 0,2357 | 0,3184 | 0,3545 | 0,3530 | 0,3088 | 0,3316 | 0,2923 | 0,2348 | 0,3210 |
| | | | | | | | | | | | | | | | |
| Expected number of beds nu | 68,3806 | 79,6193 | 73,1796 | 77,6065 | 71,4388 | 61,6775 | 53,8272 | 67,8300 | 76,7010 | 76,1481 | 68,5272 | 76,7643 | 68,0576 | 57,5772 | |
| Patients hospitalized during current cycle at NU | 24,7782 | 46,5585 | 47,1228 | 57,5840 | 55,8822 | 50,4612 | 45,3279 | 61,2933 | 71,7981 | 72,6740 | 66,0984 | 75,2095 | 66,9998 | 57,0770 | |
| Patients hospitalized in earlier cycles at NU | 43,6024 | 33,0608 | 26,0568 | 20,0226 | 15,5566 | 11,2163 | 8,4993 | 6,5367 | 4,9029 | 3,4741 | 2,4288 | 1,5548 | 1,0578 | 0,5001 | |
| | | | | | | | | | | | | | | | |
| C nu,d,hz * R nu,d (max available capacity) | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | |
| | | | | | | | | | | | | | | | |
| Bed occupancy NU | 0,8548 | 0,9952 | 0,9147 | 0,9701 | 0,8930 | 0,7710 | 0,6728 | 0,8479 | 0,9588 | 0,9519 | 0,8566 | 0,9596 | 0,8507 | 0,7197 | 0,8726 |
| | | | | | | | | | | | | | | | |
| Expected number of hours dc | 8,8162 | 8,0562 | 8,2770 | 101,4552 | 226,6975 | | | 8,8162 | 8,0562 | 8,2770 | 194,8643 | 9,5002 | | | |
| Expected number of beds dc | 0,6297 | 0,5754 | 0,5912 | 7,2468 | 16,1927 | | | 0,6297 | 0,5754 | 0,5912 | 13,9189 | 0,6786 | | | |
| C dc,d * R dc,d (max available capacity) | 980 | 980 | 980 | 980 | 980 | | | 980 | 980 | 980 | 980 | 980 | | | |
| | | | | | | | | | | | | | | | |
| Bed occupancy DC | 0,0090 | 0,0082 | 0,0084 | 0,1035 | 0,2313 | | | 0,0090 | 0,0082 | 0,0084 | 0,1988 | 0,0097 | | | 0,0595 |

*Table 45: Model results scenario 3 (Heerlen)*

## Scenario 4: Changing the maximum bed capacity at the nursing unit (2)

| Variable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | SUM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X 1,1,d | 8 | 6 | 6 | 0 | 6 | | | 16 | 8 | 6 | 0 | 1 | | | 57 |
| X 2,1,d | 4 | 1 | 0 | 1 | 1 | | | 0 | 0 | 3 | 2 | 5 | | | 17 |
| X 3,1,d | 0 | 0 | 0 | 3 | 0 | | | 0 | 0 | 0 | 5 | 0 | | | 8 |
| X 4,1,d | 6 | 0 | 7 | 0 | 0 | | | 0 | 0 | 0 | 0 | 0 | | | 13 |
| | | | | | | | | | | | | | | | |
| X1,2,d | 0 | 4 | 0 | 0 | 0 | | | 0 | 0 | 1 | 0 | 10 | | | 15 |
| X2,2,d | 0 | 0 | 0 | 0 | 2 | | | 0 | 0 | 0 | 0 | 0 | | | 2 |
| X3,2,d | 0 | 1 | 0 | 5 | 3 | | | 0 | 0 | 0 | 0 | 0 | | | 9 |
| X4,2,d | 1 | 0 | 0 | 8 | 10 | | | 0 | 5 | 0 | 9 | 5 | | | 38 |
| | | | | | | | | | | | | | | | |
| δ- ic,d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| δ- nu,d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| δ- dc,d | 0 | 0 | 0 | 0 | 0 | | | 0 | 0 | 0 | 0 | 0 | | | 0 |
| | | | | | | | | | | | | | | | |
| δ+ ic,d | -14 | -13 | -13 | -14 | -14 | -15 | -16 | -14 | -14 | -13 | -14 | -14 | -15 | -16 | |
| δ+ nu,d | -1 | 0 | -3 | 0 | 0 | -9 | -18 | -4 | 0 | 0 | 0 | 0 | -8 | -16 | |
| δ+ dc,d | -69 | -66 | -69 | -62 | -61 | | | -69 | -67 | -69 | -65 | -61 | | | |
| SUM surplus | 2520 | 2370 | 2550 | 2280 | 2250 | 720 | 1020 | 2610 | 2430 | 2460 | 2370 | 2250 | 690 | 960 | 27480 |
| | | | | | | | | | | | | | | | |
| δ+ nu hz,d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| SUM wrong hz | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | SUM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Required | 35,8657 | 22,219 | 22,4026 | 21,7629 | 30,9562 | | | 35,608 | 22,2625 | 21,7083 | 22,0994 | 31,4045 | | | |
| | | | | | | | | | | | | | | | |
| C orblock,d * L orblock (max available capacity) | 36 | 22,5 | 22,5 | 22,5 | 31,5 | | | 36 | 22,5 | 22,5 | 22,5 | 31,5 | | | |
| OR occupancy | 0,9963 | 0,9875 | 0,9957 | 0,9672 | 0,9827 | | | 0,9891 | 0,9894 | 0,9648 | 0,9822 | 0,9970 | | | 0,9852 |
| | | | | | | | | | | | | | | | |
| Expected number of beds ic | 6,9132 | 7,5142 | 7,5555 | 6,8713 | 6,9739 | 6,1599 | 5,1316 | 6,7514 | 7,3138 | 7,5224 | 7,0860 | 7,2470 | 6,1279 | 5,2164 | |
| Patients hospitalized during current cycle at IC | 2,5785 | 3,6496 | 4,2993 | 4,0833 | 4,6412 | 4,0305 | 3,4537 | 5,2806 | 6,0696 | 6,8236 | 6,6816 | 7,0854 | 6,0067 | 5,1659 | |
| Patients hospitalized in earlier cycles at IC | 4,3347 | 3,8646 | 3,2562 | 2,7880 | 2,3327 | 2,1293 | 1,6779 | 1,4708 | 1,2441 | 0,6988 | 0,4044 | 0,1616 | 0,1213 | 0,0505 | |
| | | | | | | | | | | | | | | | |
| C ic,d*R ic,d (max available capacity) | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | |
| | | | | | | | | | | | | | | | |
| Bed occupancy IC | 0,3292 | 0,3578 | 0,3598 | 0,3272 | 0,3321 | 0,2933 | 0,2444 | 0,3215 | 0,3483 | 0,3582 | 0,3374 | 0,3451 | 0,2918 | 0,2484 | 0,3210 |
| | | | | | | | | | | | | | | | |
| Expected number of beds nu | 72,5100 | 73,9749 | 70,7708 | 73,7747 | 73,9940 | 65,1075 | 56,2994 | 70,1083 | 73,9557 | 73,9923 | 73,9326 | 73,9264 | 66,2090 | 57,9817 | |
| Patients hospitalized during current cycle at NU | 28,9792 | 41,2992 | 45,4682 | 54,4519 | 59,0602 | 53,7545 | 47,5524 | 63,1664 | 68,4162 | 69,9787 | 71,1606 | 71,9948 | 64,7617 | 56,8645 | |
| Patients hospitalized in earlier cycles at NU | 43,5308 | 32,6757 | 25,3026 | 19,3228 | 14,9339 | 11,3530 | 8,7470 | 6,9419 | 5,5396 | 4,0135 | 2,7721 | 1,9316 | 1,4473 | 1,1172 | |
| | | | | | | | | | | | | | | | |
| C nu,d,hz * R nu,d (max available capacity) | 74 | 74 | 74 | 74 | 74 | 74 | 74 | 74 | 74 | 74 | 74 | 74 | 74 | 74 | |
| | | | | | | | | | | | | | | | |
| Bed occupancy NU | 0,9799 | 0,9997 | 0,9564 | 0,9970 | 0,9999 | 0,8798 | 0,7608 | 0,9474 | 0,9994 | 0,9999 | 0,9991 | 0,9990 | 0,8947 | 0,7835 | 0,9426 |
| | | | | | | | | | | | | | | | |
| Expected number of hours dc | 16,2034 | 49,0945 | 8,2770 | 109,0194 | 124,0313 | | | 8,8162 | 44,9922 | 16,5497 | 76,6691 | 129,1632 | | | |
| Expected number of beds dc | 1,1574 | 3,5068 | 0,5912 | 7,7871 | 8,8594 | | | 0,6297 | 3,2137 | 1,1821 | 5,4764 | 9,2259 | | | |
| C dc,d * R dc,d (max available capacity) | 980 | 980 | 980 | 980 | 980 | | | 980 | 980 | 980 | 980 | 980 | | | |
| | | | | | | | | | | | | | | | |
| Bed occupancy DC | 0,0165 | 0,0501 | 0,0084 | 0,1112 | 0,1266 | | | 0,0090 | 0,0459 | 0,0169 | 0,0782 | 0,1318 | | | 0,0595 |

*Table 46: Model results scenario 4 (Heerlen)*

Scenario 5: Changing the target percentage of occupied beds at the IC and DC

| Variable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | SUM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X 1,1,d | 6 | 6 | 8 | 0 | 4 | | | 15 | 7 | 9 | 0 | 2 | | | 57 |
| X 2,1,d | 4 | 0 | 0 | 3 | 3 | | | 0 | 0 | 0 | 1 | 6 | | | 17 |
| X 3,1,d | 1 | 0 | 0 | 2 | 0 | | | 0 | 0 | 0 | 5 | 0 | | | 8 |
| X 4,1,d | 8 | 0 | 3 | 0 | 0 | | | 2 | 0 | 0 | 0 | 0 | | | 13 |
| X1,2,d | 0 | 0 | 0 | 4 | 0 | | | 0 | 1 | 1 | 2 | 7 | | | 15 |
| X2,2,d | 0 | 0 | 0 | 0 | 0 | | | 0 | 0 | 1 | 0 | 1 | | | 2 |
| X3,2,d | 0 | 0 | 0 | 0 | 9 | | | 0 | 0 | 0 | 0 | 0 | | | 9 |
| X4,2,d | 1 | 10 | 0 | 7 | 2 | | | 0 | 6 | 0 | 9 | 3 | | | 38 |
| δ- ic,d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| δ- nu,d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| δ- dc,d | 0 | 0 | 0 | 0 | 0 | | | 0 | 0 | 0 | 0 | 0 | | | 0 |
| δ+ ic,d | -1 | -1 | -1 | -1 | -1 | -2 | -3 | -1 | -1 | -1 | -1 | -1 | -2 | -3 | |
| δ+ nu,d | 0 | 0 | -5 | 0 | 0 | -9 | -17 | -2 | 0 | 0 | -1 | 0 | -8 | -16 | |
| δ+ dc,d | -6 | -1 | -6 | 0 | 0 | | | -6 | -3 | -5 | 0 | 0 | | | |
| SUM surplus | 210 | 60 | 360 | 30 | 30 | 330 | 600 | 270 | 120 | 180 | 60 | 30 | 300 | 570 | 3150 |
| δ+ nu hz,d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| SUM wrong hz | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Required | 35,8738 | 22,27 | 21,6824 | 22,2304 | 29,7252 | | | 35,9681 | 22,2241 | 22,4947 | 22,3369 | 31,4835 | | | |
| C orblock,d * L orblock (max available capacity) | 36 | 22,5 | 22,5 | 22,5 | 31,5 | | | 36 | 22,5 | 22,5 | 22,5 | 31,5 | | | |
| OR occupancy | 0,9965 | 0,9898 | 0,9637 | 0,9880 | 0,9437 | | | 0,9991 | 0,9877 | 0,9998 | 0,9928 | 0,9995 | | | 0,9860 |
| Expected number of beds ic | 6,7889 | 7,1409 | 7,3713 | 7,1209 | 7,3483 | 6,3947 | 5,3671 | 6,9001 | 7,2939 | 7,2295 | 6,6652 | 7,2217 | 6,2612 | 5,2808 | |
| Patients hospitalized during current cycle at IC | 2,4699 | 3,3362 | 4,1245 | 4,3541 | 5,0656 | 4,3113 | 3,6148 | 5,3329 | 5,9825 | 6,4407 | 6,1462 | 7,0314 | 6,1118 | 5,2303 | |
| Patients hospitalized in earlier cycles at IC | 4,3189 | 3,8047 | 3,2468 | 2,7669 | 2,2827 | 2,0834 | 1,7523 | 1,5672 | 1,3114 | 0,7888 | 0,5190 | 0,1902 | 0,1493 | 0,0505 | |
| C ic,d*R ic,d (max available capacity) | 7,98 | 7,98 | 7,98 | 7,98 | 7,98 | 7,98 | 7,98 | 7,98 | 7,98 | 7,98 | 7,98 | 7,98 | 7,98 | 7,98 | |
| Bed occupancy IC | 0,8507 | 0,8949 | 0,9237 | 0,8923 | 0,9208 | 0,8013 | 0,6726 | 0,8647 | 0,9140 | 0,9060 | 0,8352 | 0,9050 | 0,7846 | 0,6618 | 0,8448 |
| Expected number of beds nu | 73,9058 | 73,9337 | 68,5657 | 73,5471 | 73,9802 | 65,2964 | 56,8429 | 71,6810 | 73,8791 | 73,9600 | 72,9313 | 73,9851 | 66,0977 | 57,8793 | |
| Patients hospitalized during current cycle at NU | 30,0877 | 40,9333 | 42,9332 | 53,8527 | 58,8419 | 53,7836 | 47,9859 | 64,7055 | 68,3814 | 70,0533 | 70,2710 | 72,2463 | 64,8127 | 56,9251 | |
| Patients hospitalized in earlier cycles at NU | 43,8180 | 33,0003 | 25,6326 | 19,6944 | 15,1383 | 11,5128 | 8,8571 | 6,9755 | 5,4977 | 3,9067 | 2,6602 | 1,7387 | 1,2850 | 0,9543 | |
| C nu,d,hz * R nu,d (max available capacity) | 74 | 74 | 74 | 74 | 74 | 74 | 74 | 74 | 74 | 74 | 74 | 74 | 74 | 74 | |
| Bed occupancy NU | 0,9987 | 0,9991 | 0,9266 | 0,9939 | 0,9997 | 0,8824 | 0,7681 | 0,9687 | 0,9984 | 0,9995 | 0,9856 | 0,9998 | 0,8932 | 0,7822 | 0,9426 |
| Expected number of hours dc | 16,2034 | 81,9282 | 8,2770 | 94,9855 | 95,8021 | | | 8,8162 | 60,6521 | 24,9580 | 93,2145 | 97,9790 | | | |
| Expected number of beds dc | 1,1574 | 5,8520 | 0,5912 | 6,7847 | 6,8430 | | | 0,6297 | 4,3323 | 1,7827 | 6,6582 | 6,9985 | | | |
| C dc,d * R dc,d (max available capacity) | 98 | 98 | 98 | 98 | 98 | | | 98 | 98 | 98 | 98 | 98 | | | |
| Bed occupancy DC | 0,1653 | 0,8360 | 0,0845 | 0,9692 | 0,9776 | | | 0,0900 | 0,6189 | 0,2547 | 0,9512 | 0,9998 | | | 0,5947 |

*Table 47: Model results scenario 5 (Heerlen)*

# E. Interviews

Section E.1 shows the questions and way of working during the interviews with the care planning in Sittard and with the OR planner in Heerlen. Section E.2 shows the questions used in the interview with the outpatient departments and section E.3 shows the questions used in the interviews with the central planning in Sittard and with the hospitalization office in Heerlen.

## E.1 Interviews Care planning and OR planner

The interviews with the care planning in Sittard and the OR planner in Heerlen are based on the same questions and way of working. In order to be sure that answers to the questions were as expected and for both locations in the same direction, a simple representation of a clinical pathway was made and presented during the interview. Together with the care planning in Sittard and the OR planner in Heerlen, the clinical pathways for both locations were extended. In this way it was possible to create clinical pathways which are unique to both locations. Another possible way of working was to show the clinical pathway of Sittard to the OR planner in Heerlen; however, the possibility existed that the OR planner would say that the clinical pathway of Heerlen was the same as the clinical pathway of Sittard. Both interviews show that this is not the case, there are much differences between both clinical pathways and the way of planning patients. Section E.1.1 shows the questions used in the interviews with the care planning and the OR planner.

### *E.1.1 Questions used in the interviews with the care planning and OR planner*

Figure 4 laat een algemeen klinisch pad zien dat een patiënt binnen chirurgie in mijn ogen kan doorlopen. Op deze manier wil ik in kaart proberen te brengen hoe het proces van een chirurgie patiënt er daadwerkelijk uit ziet. Dit proces zal verder uitgediept moeten worden door het resource gebruik van een chirurgie patiënt hieraan te koppelen. Voor zowel Sittard als Heerlen zal dit in kaart gebracht worden, hierna zal bepaald worden welke manier van werken het meest efficiënt is en dus gebruikt moet worden in de fusie organisatie. Figure 4 is uiteraard niet compleet, ik ben benieuwd hoe de manier van plannen in het proces dat de patiënt in Sittard/ Heerlen door loopt er uit ziet.

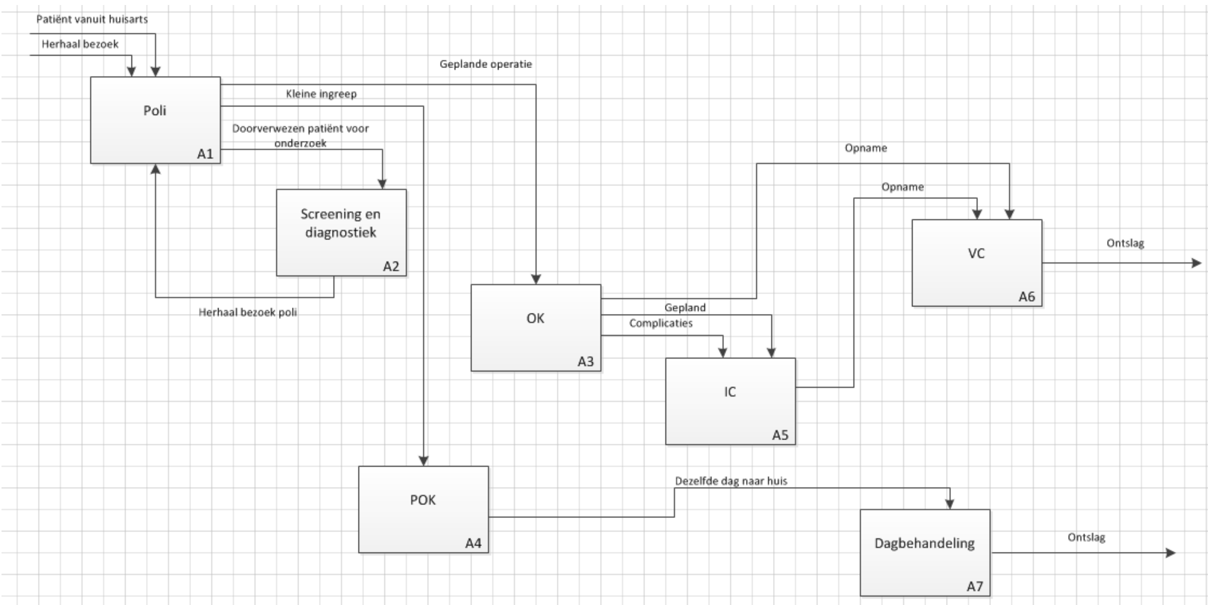


*Figure 4: Simple representation of a clinical pathway*

- Wat houdt uw werk in?
- Hoe komt de patiënt terecht op de poli? Wie plant de afspraak van de patiënt op de poli?

- Hoe ziet het zorgpad (proces door het ziekenhuis) er uit voor patiënten van chirurgie (vanaf poli tot naar huis gaan)?
- Wanneer de chirurg de diagnose gesteld heeft op de poli wat gebeurd er dan? Wie zijn hierbij betrokken?
- Zijn er bottlenecks aan te wijzen binnen het zorgpad dat een patiënt doorloopt?
- Hoe wordt de zorg voor een patiënt gepland?
- Wie plant de zorg voor een patiënt?
- Wordt de zorg voor een patiënt voor het gehele traject meteen gepland?
- Hoe ziet de manier van plannen er uit?
- Op welke manier worden resources toegewezen (korte termijn)?
- Hoe wordt het aantal resources bepaald op lange termijn?
- Hoe wordt bepaald hoeveel tijd er per patiënt ingepland moet worden (operatie duur, verpleegduur etc)?
- Hoe lang duurt een OK dagdeel (tijden)? Hoe lang duurt een OK dag?
- Hoe zit het met Spoed patiënten? Wordt hier al rekening mee gehouden in de OK planning?
- Wanneer wordt bepaald dat het OK schema voor de komende week kloppend is?

## E.2 Interviews outpatient department

Figure 4 was also shown to the outpatient department assistants at both locations in order to create more complete clinical pathways for Sittard and Heerlen. The questions displayed beneath were asked to the outpatient department assistants.

- Wat houdt uw werk in?
- Hoe komt de patiënt terecht op de poli? Wie plant de afspraak van de patiënt op de poli?
- Hoe ziet het zorgpad (proces door het ziekenhuis) er uit voor patiënten van chirurgie (vanaf poli tot naar huis gaan)?
- Wanneer de chirurg de diagnose gesteld heeft op de poli wat gebeurd er dan? Wie zijn hierbij betrokken?
- Welke onderzoeken plannen jullie voor de patiënt?
- Welke onderzoeken worden het meeste ingepland?
- Wat gebeurd er met de patiënt nadat de onderzoeken uitgevoerd zijn?
- Hoe werkt het plannen van de POK afspraken?
- Kan de patiënt vanuit de POK naar de dagopname?
- Wat gebeurd er na de POK met de patiënt, moet deze altijd op herhaal bezoek komen op de poli?
- Zijn er bottlenecks aan te wijzen binnen het zorgpad dat een patiënt doorloopt?

- Hoe ziet de manier van plannen er uit? Wie maakt de planningen voor de poli?
- Hoe ver van tevoren zijn de planningen bekend? Veranderen de planningen vaak?
- Hoe wordt bepaald hoeveel tijd er per patiënt ingepland moet worden? Is hier een standaard tijd voor?
- Wat is de taak van de spreekuur assistenten?
- Wat is de taak van de specialistische verpleegkundigen en de nurse practitioners?
- Wat doen zij anders voor de patiënt dan de polikliniek assistenten?

## E.3 Interviews central planning and hospitalization office

The questions displayed beneath were asked to the central planning and the hospitalization office to receive more information about the bed planning.

- Wat houdt uw werk in? Wat doen jullie nog meer naast de planning van de bedden?
- Hoe ziet de beddenplanning er uit?
- Hoe ver van tevoren is deze bekend?
- Zijn de bedden beschreven voor chirurgie ook alleen maar voor chirurgie bestemd?
- Hoe weet de zorgplanning dat het bed dat ze plannen voor de patiënt ook daadwerkelijk vrij is?
- Op welke momenten wordt het beddenhuis gemonitord?
- Wanneer het beddenhuis vol ligt en een patiënt niet geplaatst kan worden wat gebeurd er dan? Wie stelt de patiënt op de hoogte?
- Vindt er vanuit de centrale planning terugkoppeling plaats naar de zorgplanning/ OK planner?
- Plannen jullie alle bedden, dus dagverpleging en klinisch?
- Waarom staat de planning van de bedden los van het plannen van de OK datum en de rest van de afspraken nodig voor de OK kan plaats vinden?
- Wie bepaalt de ligduur van een patiënt?

# F. The planning process (Detailed version)

Appendix F describes the planning process of Sittard and Heerlen. The differences in the way of planning at both locations should become clear in appendix F. For every important unit in the planning process, the way of working at both locations is discussed in section F.1 to F.7.

## F.1 Outpatient department Sittard

There are different ways in which the patient can enter the process flow, either via the outpatient department or via the emergency department (Figure 1 in section 3.1.1)

The inputs of the outpatient department:

- A referral by the general practitioner
- An internal referral
- A referral from another hospital
- A re-visit
- Results of clinical investigations
- A direct referral by the emergency department

The general practitioner registers the patient in zorgdomein, this is a database with all patients demanding for an appointment at the outpatient department. The patient has to call the outpatient department to schedule an appointment. When a patient did not call within ten days, the outpatient department secretary call those patients. The unique zorgdomein number is used to verify the patients at their first visit to the outpatient department.

When the patient is referred internally, the patient has to visit the outpatient department secretary of surgery to schedule an appointment.

At the day of the appointment the patient goes to the central registration point for surgery and is directed to the waiting room for the surgery outpatient department. The outpatient department assistants call the patient from the waiting room into a treatment room and leave the treatment room to the back office to call the surgeon. The surgeon tries to determine the right diagnosis.

This diagnosis can consist of:

- Further investigations are needed to determine the right diagnosis
- A referral to the policlinic operating room (POR)
- A referral to the care planning to schedule an appointment for surgery
- End of treatment, the patient leaves the process flow
- Urgent hospitalization

The surgeon leaves the treatment room to the back office and the outpatient department assistant enters the treatment room to schedule all the appointments for the patient. The appointments for a CT scan or other clinical investigations are scheduled together with the patient.  A MRI scan cannot be scheduled by the outpatient department assistant, the patient receives a request for the MRI at home. In this case, the patient has to call the outpatient department of surgery to schedule a re- visit appointment to receive the results of the MRI scan. When the patient needs a consult at another department for example; cardiology, the outpatient department assistant has to call this specific department to schedule an appointment for the patient. The outpatient department of surgery is not allowed to schedule appointments in the agendas of other specialism. So the patient almost always leaves the outpatient department with all appointments for further clinical investigations or consults and an appointment for a re- visit to the outpatient department of surgery. When no further investigations are needed, the patient is directly referred to the care planning when a clinical operation is needed. In this last case the outpatient department assistant gives the patient the pre- operative screening questionnaire which can be filled while waiting for the appointment with the care planning.

Every day the operating room schedule is checked by the outpatient department assistants, in order to be able to schedule the re- visit appointments at the outpatient department for the patients operated during that day. The re- visit appointment is given to the patient at his/ her dismissal from the nursing unit. This is not the way of working for all OR programs, sometimes the nursing unit has to call the outpatient department assistants, after the surgeon gave permission, to schedule the re- visit appointment.

The outpatient department assistants schedule the appointments at the POR except the laser treatments, those are planned by the care planning. The appointment for re- visit at the outpatient department is scheduled immediately.

The outpatient department secretary makes the outpatient department agenda available when the secretary of surgery has released the planning of the surgeons. The outpatient department assistants are able to schedule patient appointments two months ahead. One of the outpatient department assistants makes the POR agenda available which also depends on the release of the surgeons' planning. The POR agenda does not change much; however, the outpatient department agenda can change every day, so one should pay extra attention to those changes.

In case of an urgent hospitalization, the outpatient department assistant has to call the central planning to ask whether a clinical bed is available at the surgery nursing unit or anywhere else. The central planning notifies the nursing unit with the available clinical bed about the urgent hospitalization.

### F.2 Outpatient department Heerlen

Patients can enter the process flow either via the outpatient department or via the emergency department. The schedule of the outpatient department is based on the surgeons' planning which becomes available for three months ahead (Figure 2 in section 3.1.1)

The inputs of the outpatient department:

- A referral by the general practitioner
- A direct referral by the emergency department
- A referral by the night care
- An internal referral
- A re- visit
- A second opinion
- Results of clinical investigations

After a referral by the general practitioner, there are two options; either the patient has to call the outpatient department to schedule an appointment or the general practitioner has to send the referral letter by email to the outpatient department. This email address is checked once a day by the outpatient department secretary. Patients receive an appointment request at home. When the appointment cannot be scheduled within one week, the outpatient department calls the patient to schedule an appointment.

After diagnosing and screening the patient, the surgeon can choose between several options:

- A referral to the hospitalization office (bureau opname) when a clinical operation is needed.

- A referral to the policlinic operating room
- End of treatment, the patient leaves the process flow
- Urgent hospitalization at the emergent hospitalization department (EHD)
- Further investigations are needed to determine the right diagnosis

Appointments at the POR are scheduled by the outpatient department assistants. The POR schedules the appointment for re- visit at the outpatient department. When there are no free spaces in the agenda of the outpatient department, the POR has to call the outpatient department to schedule an appointment for re- visit in this way.

When further clinical investigations or other consults are needed to be able to determine the right diagnosis, the outpatient department assistants send requests for the clinical investigations and consults to the specific departments. At home the patient waits for the appointment request for the clinical investigations. When the patient has received this appointment request, the patient has to call the outpatient department to schedule an appointment for a re- visit. When those further investigations are urgent, the outpatient department assistant calls the specific department for those investigations and schedules the appointment immediately. In this case, the appointment for re- visit to the outpatient department can be scheduled immediately.

At the day of dismissal from the nursing unit, the patient receives the appointment for re- visit at the outpatient department.

## F.3 Planning differences at the outpatient departments

When comparing the planning processes at the outpatient department at Sittard and Heerlen some differences can be seen.

- Patients referred by the general practitioner to the outpatient department in Sittard receive a zorgdomein number for verification principles, this is not the case when patients are referred to the outpatient department in Heerlen.

- When further investigations are needed to determine the right diagnosis, the outpatient department assistants in Sittard schedule all the appointments together with the patient, also the appointment for re- visit at the outpatient department is scheduled. The outpatient department assistants in Heerlen send requests for those clinical investigations or other consults to the specific departments. The patient receives an appointment request for the clinical investigations or consults at home. After this the patient has to call the outpatient department to schedule an appointment for re- visit.

- The appointment for re- visit after the POR is scheduled immediately by the outpatient department assistants in Sittard. In Heerlen, the appointment for re- visit at the outpatient department is scheduled by the POR after the treatment has been completed.

## F.4 Care planning Sittard

When a clinical operation is needed, the patient is referred to the care planning. In this case, the surgeon has to fill the OR request and the outpatient department assistant schedules an appointment for the patient at the care planning. The patient has to fill the pre- operative screening questionnaire while waiting for the appointment with the care planning.

Activities of the care planning:

- Creating the OR schedule

The amount of OR time per specialism is decided by the board every year again. This amount of OR time, together with the OR week schedule and the surgeons planning is used to create an OR schedule. This schedule can be used to plan patients three months ahead. The care planning in Sittard and the OR planner in Heerlen have a meeting every three months to discuss the planning of the surgeons and the related OR schedule. When one of both locations is not able to fill some time slots, the care planning and OR planner will discuss if surgeons can be moved to other days. When all time slots are divided, the care planning and the OR planner are able to create an OR schedule divided to sub specialism for three months ahead.

In Sittard the OR schedule is a so called white gabs planning, this means that every day 90 minutes are allowed to remain unscheduled for the urgent patient flow. Besides that 240 minutes per week are allowed to remain unscheduled for the semi- urgent patients of both the vascular surgery and the trauma surgery. Every available operating room for surgery can be scheduled for 480 minutes a day, from 08:15 am till 16:15 pm. The morning program starts at 08:15 am and ends at 12:15 pm, the midday program starts at 12:30 pm and ends at 16:15 pm, so 240 minutes in the morning and 225 minutes in the midday.

- Scheduling of the OR appointment together with the patient.

The OR request filled by the surgeon is used to determine which type of clinical operation is needed, which surgeon should operate the patient and other important facts about the patient. The duration of the surgical operation is determined by the surgeon, there are no standard time slots per surgical operation type. The care planning scores the surgeons every clinical operation, those actual scores are compared with the expected operation durations. When there are much differences, the care planning schedules more or less time for the clinical operation than the surgeon requests. Also the use of an intensive care bed is filled on the OR request.

- Checking the pre- operative screening questionnaire

The POS questionnaire is used to determine if the patient has some bacteria which should be eliminated before surgery. When the patient has answered yes to one of the questions, the care planning has to schedule an appointment to take a biopsy in order to be sure about the condition of the patient before surgery.

- Scheduling of the POS appointment together with the patient

All patients with an OR request, first need to visit the pre- operative screening before the surgical operation can be executed. Patients for daycare treatments have the choice to either visit the pre-operative screening or not. When the patient does not decide to visit the pre- operative screening, the care planning sends the patient files to the pre- operative screening (paper screening) just in case the anesthesiologist does want to examine the patient before the daycare treatment. When the anesthesiologist wants to examine the patient before treatment, the care planning has to the call patient and schedule an appointment at the POS. When no investigations based on protocol are needed, the patient can be scheduled for the POS right after the appointment with the care planning.

- Scheduling of appointments for investigations based on protocol before the POS appointment

When the care planning has to schedule an appointment at the operation theatre for a man aged 50 or a woman aged 60, some blood tests and other investigations have to be done according to a protocol.

- Checking the POS consultation hour

Every day the care planning has to check the consultation hour of the pre-operative screening of the day before. Sometimes the anesthesiologist requests for further investigations, in this case the care planning calls the patient and schedules the appointments.

- Scheduling of POR appointments

Some of the appointments (laser treatment and evlt) at the policlinic operation theatre are scheduled by the care planning.

- Scheduling of the appointment at the pediatric department and pedagogic care department

The care planning also have to schedule surgical operation appointments for children. Children first have to visit the pedagogic care department which prepares the children for their treatment. This path is followed by all children under 18 for daycare treatments as well as for clinical treatments. Children under the age of 1 year old also have to visit the pediatric department, to be sure that those young children are healthy. The children follow the same path as the other patients after their visit to the pedagogic care department, so pre-operative screening or paper screening.

- Creating a balanced use of clinical beds and daycare beds

The planning of the beds at the nursing unit is not the responsibility of the care planning, this is the responsibility of the central planning. The care planning should create a balanced use of clinical beds and daycare beds. The care planning estimates the expected length of stay at the nursing unit, this is done based on experience. Every Thursday the operating room planning of the next week is discussed with the care planning, the central planning and the floor manager of the operation theatre. During this meeting the feasibility of the operating room planning is discussed, when problems can arise at the nursing unit of surgery, patients can be moved to other departments ("vreemdliggers") or patients are cancelled. The operating room planning will be frozen for the next week. When requests for OR appointments arrive for clinical or daycare treatments for that week, the care planning has to call the daycare department, the operation theatre department and the central planning to confer the situation.

- Providing information about the clinical operation to the patient

The patient receives a letter with all important appointments and also information about the surgical operation to be prepared well. The patient has to call the care planning the day before the surgical operation, to receive information about the time the patient is expected at the hospitalization department and his/her physical condition. The order in which patients are operated is decided the day before. For this reason the patient has to call the care planning.

### F.5 Central planning Sittard

The central planning is concerned with the patient logistics inside the hospital. Every year the subdivision of the beds per specialism is provided by the board. This scheme is divided in quarters which contain reduction weeks (holiday).

Important activities around patient logistics are:

- Creating enough space at the nursing unit for all new hospitalizations

When there is not enough space at the nursing unit of surgery for a new hospitalization, the central planning tries to move the patient to another nursing units. When this is the case, an email is sent to the care planning because it is the responsibility of the care planning to call the patient and inform the patient about the change in nursing unit. When the OR schedule is delayed and one of the planned patients should be cancelled, the care planning has to call this patient. The care planning should inform the central planning about the cancelled patient, because the planned bed can be used for another patient. The aim is to create enough space for all planned hospitalizations, in this case the planned hospitalizations get priority over the urgent hospitalizations.

- Taking care of internal transfers and transfers from other hospitals
- Taking care of urgent hospitalizations via the outpatient department or via the emergency department

The outpatient department and the emergency department have to call the central planning to inform them about the urgent hospitalization. The central planning creates space for the urgent hospitalization at the nursing unit and calls the nursing unit to inform them about the urgent hospitalization. When there is no bed available or the patient needs some further investigations before hospitalization, the patient is transferred to the observatorium. The patient should leave this department within 24 hours, either to the OR or to the nursing unit. The transfer to the OR is the responsibility of the care planning and the transfer to the nursing unit is the responsibility of the central planning. The urgent patient flow can be seen as 2/5 of the total patient flow.

- Checking the OR schedule

Every Thursday the OR schedule is discussed with the floor manager of the OR, with the care planning and with the central planning. When the central planning agrees with the OR schedule for the next week (mo-fri) based on the number of new hospitalizations, the OR schedule for the planned surgical operations will be frozen. When a semi- urgent patient has to be scheduled for surgical operation during that week, the care planning has to call the central planning to ask whether a bed is available at the nursing unit. The OR planning for the current day till 10:00 am the next day needs to be ensured.

It is also the responsibility of the central planning to ensure that the OR schedule is fully planned. When this is not the case for several weeks, that specific specialism should remise those time slots. Other specialism who structurally have not enough time slots, can subscribe for those under used time slots.

During the week, no beds are reserved for the urgent patient flow; however, the central planning knows based on experience how much beds are needed for the urgent patient flow.

- Collecting the production monitoring numbers

When a specialism has too much hospitalizations based on a pre-defined norm, the central planning informs the secretary of this specialism about this fact.

- Collecting the outpatient department waiting times and the waiting times for surgical operations and daycare treatments

Every Monday the central planning collects the waiting times of the outpatient department, which are also visible for patients at the website of the hospital. Every month the central planning collects the waiting times for some surgical operations and daycare treatments which are also visible at the website.

- Daily checking of the bed occupancy at the nursing units

The bed occupancy at the nursing units is checked much during the day. The number of dismissals and internal transfers during the day should equalize the number of new hospitalizations.

### F.6 Hospitalization office Heerlen

When a surgical operation is needed, the patient is referred to the hospitalization office with or without an OR appointment. The surgeon has to fill the hospitalization form with all specifications about the surgical operation; for example, the expected OR duration, which type of surgical operation, which surgeon, need of IC bed, particularities of the patient and the expected length of stay at the nursing unit.

Every year the subdivision of the beds per specialism is provided by the board. This scheme is divided in quarters which contain reduction weeks (holiday). The scheme is not the same for every day, because not all specialism operate every day.

The activities of the hospitalization office:

- Arranging the OR appointment

So a patient can enter the hospitalization office with or without an OR appointment. Sometimes when the surgical operation should be performed urgently, the surgeon contacts the OR planner about the OR appointment immediately. In this case, the patient already has an OR appointment when the patient is referred to the hospitalization office. When this is not the case, the hospitalization office places the patient on the waiting list for the determination of the OR appointment. This waiting list is visible for the OR planner, which schedules the OR appointments for the patients of surgery.

- Scheduling of appointments for investigations based on protocol

When the patient does not have an OR appointment yet, the POS appointment cannot be scheduled at the moment because the result of the POS is only three months valid. The appointments for investigations based on protocol or other investigations are scheduled for the patient, the results of those investigations should be known before the POS appointment takes place.

- Scheduling of the POS appointment and creating space for hospitalization at the nursing unit

When the OR planner has scheduled the patient, the hospitalization office can schedule the POS appointment and arrange the hospitalization at the nursing unit. The hospitalization office sends a letter to the patient with the OR appointment and the POS appointment. It is also the responsibility of the hospitalization office to inform the nursing unit about new hospitalizations.

When a patient is registered at the POS, the POS is responsible for the patient till the moment of surgical operation. It is possible that the anesthesiologist requests for extra investigations or consults at other departments, the anesthesiologist assistant schedules the appointments for those extra investigations. All patients, clinical and daycare, should visit the POS, there is no paper screening for daycare patients. When the anesthesiologist does want an IC bed for the patient against the wishes of the surgeon, the hospitalization office is informed by the POS to schedule an IC bed for that patient. The POS also informs the hospitalization office about the extra investigations or consults. The results of the extra investigations or consults are sent by a digital letter to the POS.

- Daily checking of the bed occupancy at the nursing units

The bed occupancy at the nursing units is checked much during the day. The number of dismissals and internal transfers during the day should equalize the number of new hospitalizations. The hospitalization office checks the waiting list system in which the surgical operations/ hospitalizations of the next day are visible. The OR planner schedules patients for OR without concerning about available beds. Every day the OR planning for the next day is checked to determine whether this fits with the available beds at the nursing unit. When the nursing unit of surgery does not have enough space, the patient is moved to another nursing unit or sometimes the patient is cancelled.

- Taking care of urgent hospitalization transfers

The urgent patient flow enters the process via the outpatient department or the emergency department. In case of an urgent hospitalization, the patient is hospitalized at the emergent hospitalization department (EHD). When the patient leaves the hospital within 24 hours, the patient stays at the EHD, when the length of stay is longer than 24 hours, the hospitalization office arranges the transfer to the nursing unit. It is the responsibility of the OR planner to schedule the patient for OR when this is needed. All urgent patients are first hospitalized at the EHD before hospitalization at the regular nursing units.

- Checking the OR schedule

When the patient is informed about the OR appointment, the date and time are known. Every Thursday the OR planner and the hospitalization office discuss the OR planning for the next week (mo- fri) based on the available beds in the nursing unit. When times of OR appointments are changed, depended on the arrangement with the patient, either the patient calls the hospitalization office, or the hospitalization office calls the patient.

### F.7 OR planner Heerlen

The OR planner in Heerlen only schedules the OR appointments for patients of surgery.

The activities of the OR planner:

- Creating the OR schedule

The amount of OR time per specialism is decided by the board every year again. This amount of OR time, together with the OR week schedule and the surgeons planning is used to create an OR schedule which is used to plan patients three months ahead. The OR planner in Heerlen and the care planning in Sittard have a meeting every three months to discuss the planning of the surgeons and the related OR schedule. When one of both locations is not able to fill some time slots, the OR planner and care planning will discuss if surgeons can be moved to other days. When all time slots are divided, the OR planner and the care planning are able to create an OR schedule divided to sub specialism for three months ahead.

The OR schedule is not filled entirely, it is a so called white gabs schedule. Those gabs are available for the urgent patient flow; however, sometimes the gabs are already filled earlier. There is no standard number of minutes per day available for the urgent patient flow.

The morning program of the OR starts at 08:00 am and ends at 12:00 pm, the midday program starts at 12:30 pm and ends at 16:30/17:00 pm. Every day before 12:00 pm the final OR program for the next day should be completed. This final program is not sent to the hospitalization office. The OR planner calls the hospitalization office when there are changes in the OR program, the hospitalization office has to call the patient about those changes.

- Scheduling of OR appointments

At the outpatient department, the surgeon fills the hospitalization form which is sent to the hospitalization office. After the patient leaves the hospitalization office, the hospitalization form is sent to the OR planner. The OR planner schedules the OR appointment for the patient and sends the hospitalization form back to the hospitalization office. The OR planner indicates the IC bed request at the OR program. The surgeon decides about the duration of the surgical operation. The OR planner checks the patient files to be sure that those expected times are realistic. Some standard surgical operations are planned with standard operation durations, for the more difficult surgical operations more than enough time is planned.

When the anesthesiologist wants extra investigations or consults at other departments, the OR planner is informed by the POS itself or via a form from the hospitalization office.

Sometimes the surgeon calls the OR planner with the announcement of a cancelled OR, in this case the OR planner has to act immediately, because this gab should be filled with other patients. At this moment the OR planner tries to plan patients earlier if possible and to plan patients which are not planned yet because those patients are difficult to schedule.

Every Thursday the OR planning is discussed with the floor manager of the OR, to ensure that there are enough resources available to perform the OR schedule for the next week (mo- fri). The urgent patient flow can be seen as 2/3 of the total patient flow, this seems much; however, many surgical operations are now performed as a daycare surgery which provides a decrease in the number of clinical surgeries. So a large part of the total patient flow entering the hospital can be seen as part of the urgent patient flow. For this reason the OR planner should act immediately which gives an ad hoc way of scheduling patients.

- Scheduling of OR appointments for the urgent patient flow

All urgent patients are always first hospitalized at the EHD. For urgent surgical operations a special emergent OR is available during the day. Those patients are scheduled directly to the emergent OR, the OR planner is not involved in this process. When a surgical operation is not urgent and the patient is first hospitalized at the EHD or at the nursing unit, the OR planner schedules the surgical operation during the week or the same day.