The centralisation of cancer care within OncoZON

What are the effects and implications of
optimising the redistribution of cancer care surgeries
while being robust against the expected minimum volume norms?

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MSc Thesis

Tuesday, 20 June 2023

Document:

Title: 'The centralisation of cancer care within OncoZON'

Date: Tuesday, 20 June 2023

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This report was written as part of the Master thesis course of the Industrial Engineering and Management Master Programme.

Preface

" The only true wisdom is in knowing you know nothing”

Socrates

I am pleased to present this Master's thesis, which marks the completion of my Masters in Industrial Engineering and Management at the University Of Twente. This research project is the final part of my specialization in Health Care Technology and Management, following my Bachelor's degree in Technical Medicine. Throughout this research project, I have yet again come to realize that studying is not just about achieving a degree, but it more a journey of personal growth and development. I am extremely proud to have reached the end of this journey, and I look forward to the exciting opportunities that lie ahead.

I express my gratitude to Daniela Guericke for her valuable guidance and support throughout this project. Her assistance in navigating the research process has been invaluable, and I wouldn’t have reached this point without her. I also want the thank Gréanne Leeftink, my second supervisor, for providing feedback and helping me in the tails of the project.

Many thanks go to Izel Yildirim, who welcomed me to Equalis and provided daily support and guidance. I am grateful for the knowledge and experience gained through working on this project. Also, Sander Steenstraten has been an invaluable resource, sharing his extensive knowledge with me and guiding me through the health care world. I also thank Lieke Boonen for proofreading.

Finally, I thank Sanneke van der Linden for her contributions and support from the Catharina Hospital. Her willingness to assist with unexpected calls and questions has been invaluable.

I hope that this research project contributes to the field of Health Care Technology and Management, and I look forward to seeing how the challenges in this research will be dealt with in the near future.

Management summary

Introduction & problem context

The incidence of cancer in the Netherlands is on the rise, and this trend is expected to continue, leading to an increase in the demand for care. This will result in a significant cost for oncological care, accounting for almost 14% of the total healthcare budget of the Netherlands in 2040 (*Een Gezond Vooruitzicht | Volksgezondheid Toekomst Verkenning*, 2018). Currently, the healthcare industry employs around one out of six people in the country, and this number is estimated to increase to one in four by 2040, given the persisting growth in healthcare demand (Raad, 2021). In response to this situation, the Dutch government aims to improve the efficiency and quality of care by centralising high-complexity oncological care. The Integral Care Agreement (IZA), initiated by the government, proposes an increase in volume norms for a selection of tumour type surgeries in two successive 'waves', and many hospitals will not meet the required number of oncology surgeries per year. In this research the case study is about the oncology network OncoZON, with the problem owner being Catharina Hospital Eindhoven (CZE).

The challenge in allocating surgeries across OncoZON hospitals is the uncertainty around the volume norms for different tumour types, and their potential increase. This uncertainty makes it difficult to determine the best allocation strategy, as it is uncertain which combination of norms will be raised. Instead of waiting until all norms are known, CZE needs to get ready for different possibilities and have a plan in place for when the norms are revealed.

The core problem is defined as:

Catharina Hospital does not yet have sufficient insight into how the cancer care distribution within OncoZON will develop, based on the new cancer surgery volume norms and change in demand, and what the organisational effects of redistribution are.

To solve this problem, the following research question is formulated:

How can the cancer care within OncoZON be distributed given the currently available surgical capacity, while being robust against the uncertain new cancer norms and increasing demand?

Solution approach

To address the research question, a mixed-methods approach was adopted consisting of literature research, semi-structured interviews, and mathematical modelling. The literature research was used to evaluate the possible modelling approaches and to create an evaluation framework to assess the allocation outcomes of the model. Semi-structured interviews were conducted to gain insight into the boundary conditions, organisational context, and medical perspectives regarding the centralisation question. The interviews were conducted with medical professionals with expertise in the tumour types under investigation.

The surgery allocation problem in this research was formulated in a mixed-integer linear programming (MIP) model, using a robust optimisation approach. The experiment set-up aims to make the allocation solution from the MIP model robust against different norm combinations. First, all possible norm combinations were solved separately to obtain the worst-case combination in terms of objective value. Then, multiple experiments were conducted by including an increasing amount of norm combinations, first including the worst-performing combinations.

Results

The results show that the proposed model is able to find feasible surgery allocation solutions for the various norm combinations at the OncoZON hospitals. The number of care shifts (moving one surgery to another hospital) and the extra Intensive Care Unit (ICU), Operating Room (OR) and Ward capacity used are the main outcomes of interest, as they directly relate to the allocation outcome. The results show that the experiment with all norms at their maximum values resulted in the highest number of care shifts, while the experiment with all norms at their minimum value resulted in the lowest number of care shifts. Across all experiments, a maximum level of robustness was reached. The 'maximum level of robustness' means that all possible norm combinations are taken into account, making the allocation sound against all possible scenarios. In Figure 1 in current (2021) allocation is shown. To illustrate the scenario where all volume norms are maximal, Figure 2 shows how the model allocated the surgeries across OncoZON.

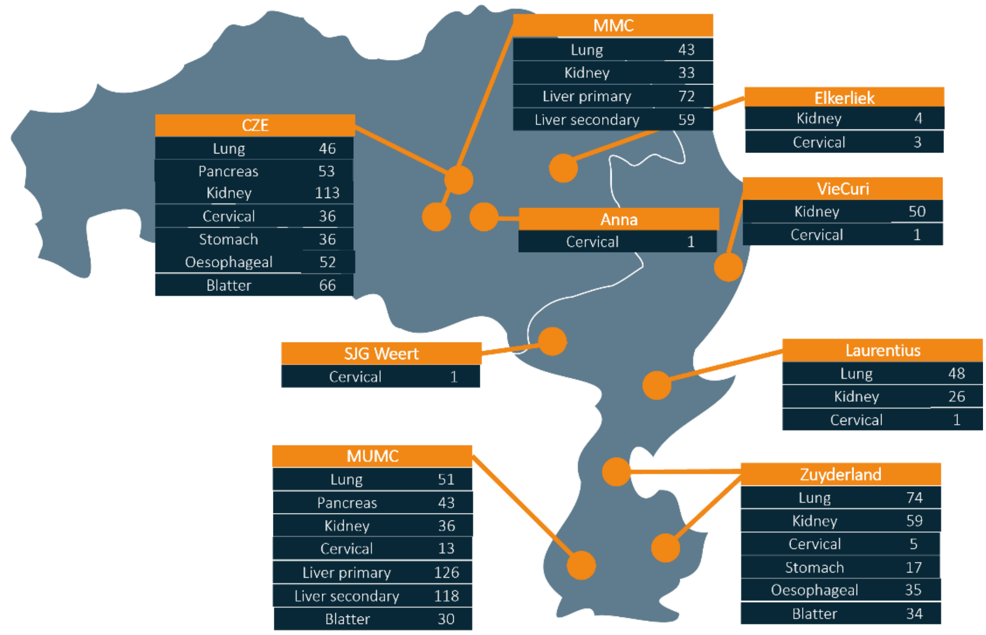

Figure 1: Surgical volumes per hospital in 2021

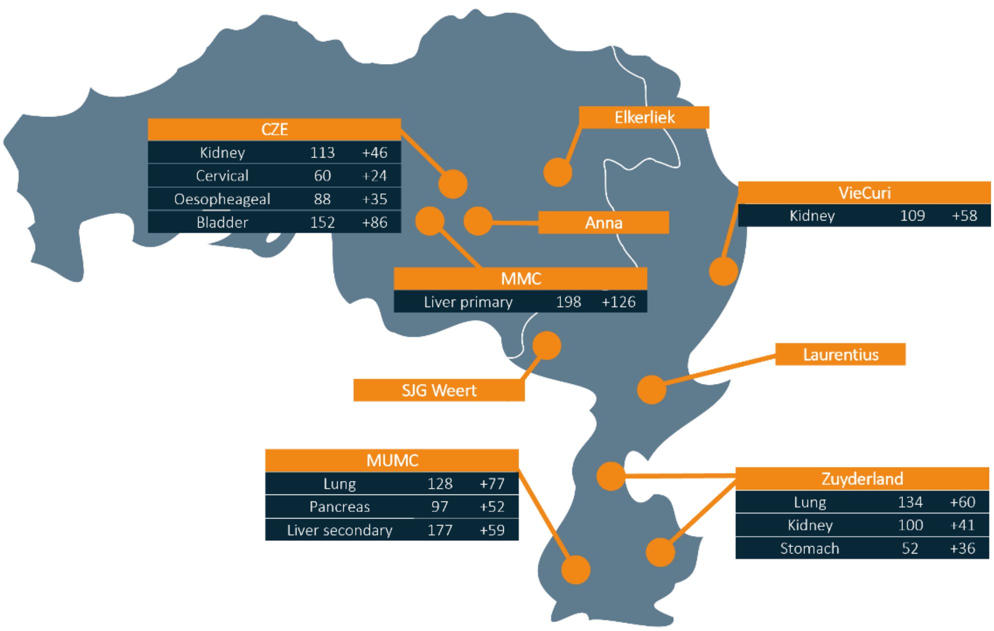

Figure 2: Surgical volumes per hospital in max norm scenario

All scenarios require extra ICU, OR, and Ward capacity in multiple hospitals, with higher volume hospitals experiencing higher capacity increases. CZE provides the main extra ICU capacity, while VieCuri and Zuyderland also use extra ICU capacity. The centralisation of pancreas and oesophageal cancer surgeries at CZE results in higher ICU usage. VieCuri requires the highest percentage of extra OR capacity due to its high kidney surgery volumes. Maastricht UMC (MUMC) needs the most additional Ward capacity due to its high lung surgery volumes. For the six most interesting scenarios, the evaluation framework was used to evaluate the resulting effects regarding the patient, hospital system and hospital profession perspective.

Patient perspective: the results indicate negative scores for travel time in all scenarios due to the centralisation of certain tumour types in either northern or southern hospitals. Increased centralisation of all tumour types is expected to lead to slightly reduced waiting times and improved surgery quality but also reduces freedom of choice due to fewer hospitals to choose from. There are minor negative impacts on organizational perspective in certain scenarios, for example where bladder surgery is shared between multiple hospitals.

Hospital system: the resource usage is slightly negative as all scenarios require extra capacity in multiple hospitals. Hospitals that have capacity savings can easily allocate them to other areas of care. However, the real challenge lies in dealing with the additional needed capacity due to shortages in staff and/or materials. In some scenarios, there is also the need for extra robotic capacity, for instance due to high bladder surgery volumes. Revenue implications vary among the scenarios and are expressed as Mean Absolute Deviation (MAD), with a minimal change of 24.9% compared to the initial revenue of the hospital. The changes in care volume are also expressed in MAD, with some scenarios having a MAD of more than 25% due to high redistributions of lung and bladder care. The sustainability of the hospital is slightly affected by whether oesophageal and stomach surgeries are provided in one hospital (positive) or separated (negative).

Medical profession: separating oesophageal and stomach surgeries may result in a slightly negative effect on the overall scores for staff composition since the workforce is better equipped to provide care for both tumour types together. Furthermore, most scenarios imply the discontinuation of certain specialists' work in several hospitals. Academic research is both positively and negatively affected by centralisation, depending on the specific type of care, with pancreas allocation at a single hospital being positive, and lung surgery discontinuation at northern hospitals being negative. In terms of (re)training and education, most staff involved in high-complexity oncology care are experienced in treating various tumour types, resulting in neutral scores.

Discussion & conclusion

The proposed model allocated surgeries across different hospitals while considering the uncertainty in the norms and using robust optimization. This study provides a valuable example of how to incorporate expert opinion and literature review to create an evaluation base that can be used to assess different scenarios for surgical allocation. It also provides a practical contribution by delivering six relevant scenarios on how the different tumour-type surgeries could be distributed across the OncoZON region. The evaluation framework developed in this research can be adapted for use in other allocation problems such as resource allocation in manufacturing or transportation.

A limitation of the study is that it only considers surgeries for the included tumour types and not the pre- and post-operative care. Another limitation is that the current total capacity use for the included tumour types were estimated, and data on total available capacity across all hospitals was not available. Additionally, the study focuses on the OncoZON region as the scope for the possible allocation of surgeries, whereas collaborations outside this oncology network are also possible.

In conclusion, this study found that scenario-robust optimization is a suitable method for modelling uncertainty in healthcare settings, and that centralising cancer surgeries would have significant consequences for patients, hospital system, and hospital profession. Additional redistribution of capacity is needed to facilitate centralisation, and decisions related to cancer care distribution should be made at regional and national levels, with a focus on quality evaluation. Furthermore, this study concludes that adopting an allocation approach to centralise cancer surgeries with the focus on minimizing care shifts and extra capacity may not necessarily yield optimal outcomes for delivering the best surgical cancer care, in terms of health outcomes and overall quality. Interviews with doctors suggest that the primary focus should be on optimizing surgery quality, even if it means centralizing all high-complexity oncology care in one hospital, rather than attempting to appease all stakeholders by redistributing tumour types across multiple hospitals.

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Glossary

Care Shifts	In the context of this research, "Care Shifts" refers to the transfer of surgeries from one hospital to another
CZE	Catharina Hospital Eindhoven, problem owner of this research
DICA	The Dutch Institute for Clinical Auditing
ICU	Intensive Care Unit, a specialized unit within a hospital that provides around-the-clock care for critically ill patients.
IZA	The Integral Care Agreement (*Dutch: **I**ntegraal **Z**org**A**kkoord*)
(Volume) Norms	In the context of this research, "Volume Norms" refers to the minimum number of surgeries for a specific tumour type that a hospital must perform each year at a single hospital location
OncoZON	Oncology network of nine hospitals and one radiotherapy institute in the South-Eastern Netherlands region (*Dutch: **Onco**logienetwerk **Z**uid-**O**ost **N**ederland)*
OR	Operating Room, a specialized room within a hospital where surgical procedures are performed.
RO	Robust Optimisation
Robustness	In this research, "Robustness" refers to the ability of a model to perform well and provide sound outcomes, despite the presence of uncertainty or variability in the expected volume norms
SONCOS	The Foundation Oncological Collaboration (*Dutch: **S**tichting **Onco**logische **S**amenwerking)*
SP	Stochastic Programming
(Tumour) Type	Refers to the specific type of cancer that a patient has, based on the location and characteristics of the tumour. In this research referred to in relation to a specific surgery type.
Ward	Designated area within a hospital where patients recover from surgery or receive post-operative care.

Chapter 1: Introduction

In **the introduction**, the outline and context of the study is presented. First, in section 1.1 the general background is explained, outlining the general reason to conduct this research. Thereafter, there is a brief overview of the organisational context, and also, in section 1.1 – 1.4 the problem context, research questions and scope are discussed. At last, in section 1.5 the reading guide is given.

1.1 General background

The number of cancer patients in the Netherlands will keep rising. Consequentially, this implies a rise in the need for surgical care. In 1989, there were just under 56,000 cancer diagnoses; by 2019, there were more than 118,000. There will be roughly 156,000 new diagnoses in 2032. This means that in ten years an average of 18 people per hour will be diagnosed with cancer (*Aantal Diagnoses Kanker Stijgt Komend Decennium Tot 156.000 per Jaar*, 2022). Following the increasing incidence of cancer at 2% per year, the cost of oncological care will rise to almost 14% of the total healthcare budget of the Netherlands in 2040 (*Een Gezond Vooruitzicht | Volksgezondheid Toekomst Verkenning*, 2018).

Due to the increase in cancer prevalence, the organisation of cancer care is under pressure. Currently around one out of six people are working in healthcare in the Netherlands (van Volksgezondheid & en Sport, 2022). Given that the growth in healthcare demand persists, the Social Economic Council estimated this proportion to grow to one in four by 2040 (Raad, 2021).

In September 2022, the Dutch government made a healthcare agreement, the Integral Care Agreement (IZA). IZA is an agreement with the aim of keeping healthcare good, accessible and affordable for the future. IZA focusses mainly on care that falls under the Health Insurance Act, and it is among other things, strongly directed to centralising certain care. There is a separate chapter in IZA, "Regional cooperation - future-proof healthcare landscape through centralisation and dispersion" which explains that the first focus will be on “centralising high-complexity oncological care and vascular surgery” (van Volksgezondheid & en Sport, 2022). This agreement has been signed by all concerned healthcare parties.

IZA names a study from the research company SiRM that studied the mortality after surgery in relation to the amount of centralisation of these surgeries. They concluded that further centralisation of eight complex, non-acute procedures could prevent around sixty deaths a year in the Netherlands for an additional twenty minutes of average travel time. Six of these procedures were cancer operations. They even went further and stated that the total impact of centralisation would be up to 200 yearly avoided deaths, as there are many more interventions for which centralisation could be possibly beneficial (de Haas et al., 2020b).

The Dutch cancer care has already established various quality norms, including minimum surgical volume requirements per hospital location. These norms mandate that each location should perform a certain minimum number of operations per year to ensure good quality care. IZA proposed a strategy to speed up the centralisation of cancer care in the Netherlands. It has been agreed that an increase in volume norms for cancer surgery will be carried out in two successive 'waves', each of which will include a variety of tumour types. From roundtable discussions that have been carried out with involved parties, it is expected that a total of 5 to 9 tumour types will be selected for the first wave, and these will be the first to have their volume norms increased.

However, as the proposed new norms focus on high-complexity oncological surgery, many hospitals currently perform low volumes of this type of care. Therefore, with the increase in volume thresholds, several hospitals do currently not meet the required number of operations per year. Additionally, the issue becomes more complex because it is not clear how much the volume requirements will be raised for each type of tumour.

This means that redistribution and centralisation of certain cancer type surgeries across several hospitals is necessary. The opportunities lie in the organisation of regional cooperation between hospitals, for example in the form of oncology networks. There already are seven anchored oncology networks in the Netherlands, which can aid in improving care for people with cancer. The oncology networks do however face major challenges: there is an urgency to organize cooperation in and between regions more vigorously in order to achieve the best possible care for every patient with cancer (Taskforce Oncologie, 2022).

Before organisational changes can be made, a general assessment of the possibility of redistributing operations between different hospitals should be made. This assessment should include a quantitative approach, evaluating the hospitals current surgical volumes and their estimated capacity, while taking into account the expected future care demand and the uncertainty in the new norm values.

To solve surgical allocation problems, mathematical modelling is one method that can be used to optimally and objectively allocate surgeries to different locations, taking into account (un)certain system constraints. This research therefore investigates the applicability of mathematical optimisation and explores its working with a case study of a specific Dutch hospital and oncology region.

1.2 Problem context

The volume norms per location for cancer surgeries will be increased. As a result many hospitals will fail to reach the volume norms, and need to start working together in referring surgeries. For this research, the problem owner is the Catharina Hospital Eindhoven (CZE). CZE was already initialising further research into the division of cancer care in their region, following the new norms and increasing demand. This research should provide insight into how the redistribution of cancer surgery could take place for CZE, and what the effects are for their hospital and the hospitals in the area. For the purpose of this study, the hospitals under consideration in this case study are those belonging to the oncology region OncoZON.

CZE wants to know what will be the possible shifts in cancer surgeries across the OncoZON hospitals, while meeting the new norms. *The challenge* is that there is a high level of uncertainty around what the exact new norms will be, which tumour types are included within the waves and what the total surgical capacity is for the other hospitals in the region. So, this research aims to tackle the following **core problem**:

Catharina Hospital does not yet have sufficient insight into how the cancer care distribution within OncoZON will develop, based on the new cancer surgery volume norms and change in demand, and what the organisational effects of redistribution are.

1.3 The research question and sub questions

To solve the core problem, a multiple-step approach is used to systematically evaluate the problem and come up with (a) solution(s). Hence, a main research question and several underlying sub-questions are defined.

Main research question

How can the cancer care within OncoZON be distributed given the currently available surgical capacity, while being robust against the uncertain new cancer norms and increasing demand?

Sub-questions

1. *How is the surgical cancer care within OncoZON currently organized and what are the expected developments?*

    1.1. What type of cancer care is provided?
    1.2. Where is the cancer care provided?
    1.3. What are the current volume and quality norms, and how is this region's performance?
    1.4. How can we estimate the capacity of the relevant hospitals? What tumour type surgeries are they able to provide?
    1.5. What are the expected changes in volume-norms for what tumour types?

2. *What can we learn from literature regarding (surgery) allocation management?*

    2.1. What are commonly used approaches for solving (regional) allocation problems?
    2.2. What is existing literature into the centralisation of (cancer) care in health care?

3. *How can we integrate the available information into a mathematical model to estimate the outcomes of feasible allocation scenarios?*

    3.1. Which type of model should be used?
    3.2. What model simplifications are needed and what assumption need to be made for the OncoZON case study?
    3.3. What is the objective and what are the boundary conditions?

4. *What are the results and the relevant effects for the hospitals?*

    4.1. What are the different model outcomes?
    4.2. What are the effects on the number of care shifts and capacity usage?
    4.3. How do the outcomes affect the patient, hospital system and hospital profession?

5. *What are the implications for the surgery organisation within OncoZON?*

    5.1. What are the conclusions and recommendations about the centralisation of surgical cancer care within OncoZON?
    5.2. What are the steps to be taken and possible future research areas for the centralisation of surgical cancer within OncoZON?

1.4 Scope

This research investigates the impact of changing demand and increased volume norms on the distribution of specific cancer surgeries in the oncology region, and to develop allocation scenarios based on mathematical modelling, expert opinion and organizational considerations.

Not all tumour types that require surgery are included, but a selection is made. The consideration for the selection is explained in Chapter 2. A broader assessment could be done to include all possible surgeries, but this falls outside of the scope, as it is less relevant for this specific problem. The research aims at including only the tumour types expected to be included in the first wave of centralisation.

This region includes a fixed amount of hospitals; in practise collaborations outside this region are also a possibility, but this falls outside the scope of this research. Also, all non-public data originates from CZE. This data is generalized and benchmarked to the other hospitals.

Regarding the modelling techniques explored, this research is limited to the exploration of mathematical modelling techniques that are able to incorporate uncertainty. Specifically, this research does not study the possibility of using simulation techniques. Simulation models such as system dynamics or queuing models are also commonly used approaches for strategic decision problems. However, due to the limited availability of data for this surgery allocation problem, incorporating simulation techniques would not provide sufficient added value in this research. The lack of detailed data on patient characteristics, surgical procedures, and resource interactions hinders the ability to accurately represent the complexities of the system in a simulation model. As a result, the focus is placed on mathematical modelling techniques that can use the available estimations of total surgical demand and rough capacity estimations per hospital.

Given that this research focuses on strategic decision-making, where stakeholders and decision-makers need clear insights, using a transparent and easily understandable approach like linear programming is important. The simplicity and clarity of linear programming models make them more accessible and practical for strategic decision-making purposes.

1.5 Reading guide

The following structure is used for this research:

In Chapter 2, the current organisation of cancer surgical care within OncoZON is described in more detail. What kind of surgeries take place where? And what are currently the volumes for every hospital? What stakeholders play a part in this problem?

In Chapter 3, the solution approach is presented. What are the possible approaches to answering the main research question? This chapter also outlines the coherence of the different research parts and explains how and why the semi-structured interviews are conducted. It also gives introduction to the Chapter for the mathematical model and evaluation framework.

In Chapter 4, the mathematical model is explained. This chapter explains the model and how the model inputs are generated. It also explains how the experiments were conducted and what the goal is of the model.

In Chapter 5, there is a framework proposed for structuring the organisational effect parameters to better evaluate the outcomes of the model. This chapter explains various prominent Dutch grey literature on centralisation serving as a bais for constructing an evaluation framework that can be used to structurally evaluate the possible allocations.

In Chapter 6, the results of the model are evaluated. It shows what the possible surgery allocations are and how these solutions relate to the framework for organisational parameters. What is the expert opinion on the results, and how do they interpret the practical feasibility of the solutions? How are the outcomes affected by changes in the model inputs?

In Chapter 7 presenting the discussion, the goal is to delve into the meaning, importance, and relevance of the results. What can we interpret from the results? What are the implications? And how are the results limited by the design of the study?

In Chapter 8, the conclusions and recommendations, the research findings are summarized, and conclusions are drawn based on the results obtained from the model and the framework. This chapter will be useful for understanding the main takeaways of the study and how they can be applied in practice to improve cancer surgical care in the OncoZON region. It also highlights areas for further research and improvements in the mathematical model to make it more accurate.

Concluding, section 1.1 points out the rise in cancer prevalence in the Netherlands. To address this rise, the Dutch government implemented the Integral Care Agreement (IZA), a healthcare agreement aimed at ensuring good, accessible, and affordable healthcare for the future. IZA focuses on centralizing high-complexity oncological care. The minimal volume norms for certain cancer surgery will be increased, leading to a redistribution of cancer surgeries among hospitals. 1.2 explains that CZE is facing the challenge of redistributing cancer surgeries across the hospitals in the OncoZON oncology region to meet the new volume norms. However, due to uncertainties regarding the specific norms, tumour types, and surgical capacity of other hospitals, CZE lacks insight into the future distribution of cancer care and the organizational impact of redistribution. This research aims to address this problem by providing clarity on the development of cancer care distribution and its organizational effects within OncoZON based on the new norms and changing demand. The research question in 1.3 is defined as how cancer care within the OncoZON region can be distributed, considering the new volume norms, changing demand, and norm uncertainty. The scope (1.4) of this research focuses is placed on exploring mathematical modelling techniques, specifically linear programming, to address the surgery allocation problem. Simulation techniques are not considered due to limited data availability, and the simplicity and transparency of linear programming models make them suitable for strategic decision-making purposes.

Chapter 2: Background & context

In the **background & context**, a detailed analysis of the background and context, with a particular focus on the current situation is given. This is done to fully grasp the topic of this thesis. Section 2.1 begins by providing historical context, followed in 2.2 by an exploration of the organizational context. The section then identifies the key stakeholders and outlines their roles. Additionally, in 2.3 it examines the inclusion criteria for a specific tumour type, analysing the current surgical volumes per hospital for these types of tumours and assessing compliance with current norms. In 2.4 the types of capacity are explained, displaying the capacity uaage per type of surgery.

2.1 History of centralisation of cancer care

In the Netherlands, and in other countries, there has long been discussion regarding whether and to what extent oncological care should be centralised. The Health Council of the Netherlands published a report titled "Quality and Division of Tasks in Oncology" in 1993. Spread care where it is ethically possible, and centralise care where it is desirable or necessary, was the starting point. National agreements on the assignment of duties, centralisation of resources, and distribution of care for a number of specialities and tumour types have been made since the publication of this Health Council report. Bone and soft tissue tumours, head and neck cancer, and haematology area cancers are a few of the first mentioned tumour types to centralise care for (Van & Zorg, 2020) .

'*To Err is Human*', a report by the US Institute of Medicine, was released in 1999. According to the authors, medical mistakes cause anywhere between 44,000 and 98,000 deaths annually in the United States (LT et al., 2000). This report has had a significant international impact and has led to programs in the Netherlands to reduce medical errors. The follow-up report was released by the Institute of Medicine in 2001: '*Overcoming the Chasm in Quality*' which stated that demand-driven (patient-centred) and as *evidence-based* as possible care should be implemented. For the first time, the necessity of transparency is mentioned. The first performance indicators in the oncology field appeared in 2003 and were focussed on breast cancer (*Crossing the Quality Chasm: A New Health System for the 21st Century*, 2001).

In 2004, internist-oncologist and medical director of the Antoni van Leeuwenhoek Hospital (AvL), Sjoerd Rodenhuis, made an appeal. He stated: "The Netherlands would have enough with twenty to 30 cancer centres, in addition to the current AvL and Daniel den Hoed Clinic" (*Centraliseren van Kankerzorg: Goed Plan | NTvG*, n.d.). This statement set many hospitals in motion: all wanted to become 'oncology centres'. In 2009, both the Dutch Institute for Clinical Auditing (DICA) and the Oncological Cooperation Foundation (SONCOS) were established. Both parties are involved in setting quality norms for cancer care. In 2012, the first SONCOS standards report with minimum standards for oncology was published. The Healthcare and Youth Inspectorate (IGZ, Dutch: Inspectie Gezondheidszorg en Jeugd) points out issues with the way oncological care is organized. There are issues with chain management, it is not always clear who enters what information into the medical record, and there is frequently no consistent point of contact for patients. KWF and IKNL, two overarching cancer institutes, collaborated to produce two monitoring reports on the standard of cancer care in the Netherlands, which were released in 2010 and 2014 (Kanker & Kankerbestrijding, n.d.). These reports stated that, despite numerous positive advancements in oncology, there are variations in treatment and results between hospitals. For rare cancer types, the authors advise centralising complex, low-volume oncology. They also think that outcome registrations and the establishment of scientific associations with professional standards are necessary (*Kwaliteitskader Organisatie Oncologische Zorg*, 2014). Overall, the centralisation of cancer care in the Netherlands started in the 1990s with a focus on improving quality of care and reducing medical errors. This process has continued to evolve over the years with the release of various reports and standards. acknowledges the advancements made in cancer care in the Netherlands, while underscoring the importance of ongoing efforts to meet the proposed norms and comes with stricter implementation deadlines to ensure development.

2.2 Organisational context

Catherina Hospital Eindhoven

Catharina Hospital, located in Eindhoven, is the largest general hospital in the area. As a top-clinical and referral teaching hospital, it offers highly specialized care at academic level, particularly in the field of oncology, which is one of its supra-regional areas of expertise. This is demonstrated through the presence of the Catharina Cancer Institute. This institute is a regional and national referral centre for breast, rectal, oesophageal, colon, pancreatic, and peritoneal cancer. Catharina Hospital Eindhoven (CZE) is the problem owner of this research.

OncoZON

OncoZON, a highly developed oncology-wide network, serves the Southeast Netherlands region. At the board level, a single umbrella cooperation agreement was signed by nine hospitals and one radiotherapy institute to form OncoZON (*Oncologisch Netwerk Zuidoost-Nederland - OncoZON*, 2023). As most of the collaborations within cancer care are organised within oncology networks, this is a logical scope of the research. However, cancer surgery collaborations are also possible to form outside of anchored oncology networks, for instance, due to geographical proximity. The reason to limit the analysis to OncoZON is that all institutions have contractually agreed to follow the same procedures and practices, which intuitively makes working together for surgeries easier to organise. Possible collaborations concerning hospitals outside of OncoZON will be discussed in the discussion of this research. shows all hospitals that are a part of OncoZON. Figure 3 shows the geographical locations of the hospitals. Maastro Clinic will not be included in further analysis of this research as it is not a hospital, but a radiotherapy centre.

Hospital	*Short name*	*City*
Anna Ziekenhuis	Anna	Geldrop
Catharina Ziekenhuis	CZE	Eindhoven
Elkerliek Ziekenhuis	Elkerliek	Helmond
Laurentius Ziekenhuis	Laurentius	Roermond
Maastricht Universitair Medisch Centrum+	MUMC+	Maastricht
Maastro Clinic	Maastro	Maastricht
Máxima Medisch Centrum	MMC	Eindhoven
St. Jans Gasthuis Weert	SJG Weert	Weert
VieCuri Medisch Centrum	VieCuri	Venlo
Zuyderland	Zuyderland	Sittard-Geleen

Table 1: All hospitals part of OncoZON

Figure 3: Geographical location of all OncoZON hospitals

Tumour types

It is important to select the right tumour types for analysis. *Figure 4* presents the timeline for the implementation of new volume norms as proposed in IZA, with two specific points in time, January 2024 and 2026, where a subset of tumour types will be chosen for an increase in norms. Following this selection, hospitals and organizations will have two years before they must comply, including meeting the requirements for insurance contracts. Hospitals should develop a strategy in advance, even though the specific tumour types and the exact norms are currently unknown. This proactive approach ensures hospitals are well-prepared in a later stage.

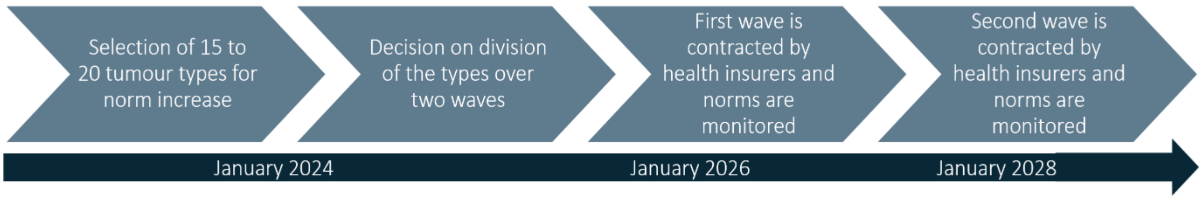

Figure 4: Process of the norm increase timeline as proposed by IZA

This research focusses on the first wave and therefore aims to include the tumour types that are expected to be included in the first wave. The argumentation behind the selection of the relevant tumour types is based on three indicators:

(1) The IZA names one prominent report as the reasoning for further centralisation of cancer care surgery, namely the 2022 SiRM report (de Haas et al., 2020a) and this report names six tumour types.

(2) The latest update from SONCOS (Hermsen, 2022) also proposes a mix of tumour types to be included in the first wave of the norm changes. This proposal includes five tumour types. This update originates from a round table discussing from the Federation Medical Specialists. In this proposal, the platform board has tried to choose a mix of tumour types so that the first

instalment of the round table discussion provides insight into the effects of centralisation at different points and from all disciplines involved.

(3) The tumour type is relevant for CZE and/or OncoZON, selected by the Cancer Institute board of CZE.

In total this resulted in 10 tumour types eligible for inclusion in this research. Table 2 shows all tumour types and the reason for inclusion or exclusion in this research. In total 9 tumour types (or sub-types) are included.

Tumour type	*Basis for including or excluding this tumour subtype*
Head and neck tumours	Excluded, due to the fact the CZE does not perform this type of surgeries and there is insufficient data available
Lung (surgery)	Included, discussed in both (1) and (2) and relevant for CZE (3)
Pancreatic	Included, discussed in both (1) and (2) and relevant for CZE (3)
Kidney	Included, discussed in (2) and relevant for CZE (3)
Cervical	Included, discussed in (2) and relevant for CZE (3)
Stomach	Included, discussed in both (1) and (2) and relevant for CZE (3)
Oesophageal	Included, discussed in both (1) and (2) and relevant for CZE (3)
Liver (primary)	Included, discussed in (1) and relevant for CZE (3)
Liver (secondary)	Included, discussed in (1) and relevant for CZE (3)

Table 2: The tumour types included and excluded for this research

2.3 Current norms

Minimum volume norms refer to the minimum number of cancer surgeries that a hospital should perform at a single location for a specific type of cancer surgery in one year. In other words, it sets a threshold for the minimum number of surgeries that a hospital should carry out in order to keep providing this type of care. If a hospital does not meet the minimum volume norm for a specific type of surgery, it is required to stop providing that particular type of care or to collaborate with other hospitals to ensure sufficient volumes. It is important to note that the cumulative surgical volume of multiple hospital locations cannot be combined to meet the minimum norm requirement. Furthermore, these norms do not consider the number of surgeries or physicians performing the procedure, although additional requirements may be necessary to ensure adequate personnel. In this study, when referring to "norms" at a specific level, such as 50 or 100, it is referring to the minimum number of surgeries of a particular type that must be performed at a single hospital location annually. There are two important organisations involved in setting the norms for cancer care, SONCOS and DICA.

SONCOS

SONCOS is an organization dedicated to improving the quality of cancer surgical care in the Netherlands. Since 2012, SONCOS has annually published the report entitled "Multidisciplinary Norms for Oncological Care in the Netherlands". This report aims to meet the needs of the professional groups of surgical oncologists, medical oncologists and radiation oncologists by defining the conditions that good oncological care should meet. The norms are part of the professional quality system of scientific medical specialist associations, which also includes guidelines, quality registrations and inspections. The input for this report comes from the medical specialist professional associations, the Nurses & Caregivers of the Netherlands, and the Dutch Federation of Cancer Patient Organizations. The report contains mandatory requirements that can apply to an oncological centre, as well as tumour-specific norms.

DICA

DICA was established in 2009. It develops clinical quality registries to improve the quality of care, increase transparency, and reduce costs. DICA provides doctors, patients, healthcare managers, and healthcare insurers with current mirror information on the quality of care and gives them the tools to learn and improve. What sets DICA apart is its CODMAN dashboard, which encompasses indicators that present all quality indicators of a registry. The CODMAN dashboard provides a clear and concise representation of the hospital's score regarding quality indicators.

Current volumes and norm performances

While SONCOS and DICA provide a broad framework with the aim of ensuring the highest possible quality of cancer care. For this research, only the volume norms per hospital location are included. In *Appendix A: Volume requirements per tumour type* the exact requirements for every type are specified. With the expectation of changing norms, it is important to see the current performance of the hospitals with respect to the current volume norms. Table 3 shows the current volume norms as well as the number of surgeries per type and per location in 2021. The table also serves to illustrate the hospitals that would fail to meet the norms of 50 (represented in light blue) and 100 (represented in orange). The illustration shows that for every tumour type some form of collaboration for allocation is needed between multiple hospitals to meet new volume requirements.

Tumour type	*Current norms*	*CZE*	*Anna*	*Elker.*	*MMC*	*MUMC*	*Lauren -tius*	*SJG*	*Vie Curi*	*Zuyd.*
Lung	20	46		0	43	51	48	0	0	74
Pancreas	20	53		0	0	43	0	0	0	0
Kidney	10	113		4	33	36	26	0	50	59
Cervical	20	36	1	3	0	13	1	1	1	5
Stomach	20	36		0	0	0	0	0	0	17
Oesophage al	20	52		0	0	0	0	0	0	35
Liver (primary)	20	0		0	72	126	0	0	0	0
Liver (secondary)	20	0		0	59	118	0	0	0	0
Bladder	20	66		0	0	30	0	0	22	34

Table 3: Current norms for all tumour types and corresponding current 2021 hospital volumes (n=10 hospitals, year: 2021, source: Ski-Tool , 2021 (MSZ, 2021), from https://www.zorginzicht.nl/openbare-data/open-data-medisch-specialistische-zorg-msz-ziekenhuizen-en-zelfstandige-behandelcentra).

2.4 Capacity

Every type of cancer surgery uses hospital capacity. For the redistribution of the cancer surgeries, it is important to take into account these different capacity types. Since the main focus of this research is on surgical capacity, three surgical-relevant types of capacity are used:

ICU

Intensive care units (ICUs) are specialized medical facilities designed to provide the highest level of care for critically ill patients. The ICU is a specially staffed and equipped, separate and self-contained area of a hospital. The ICU is specialized in constant monitoring of the vital body functions such as heart functions, blood oxygen saturation and overall pulmonary functions (Simchen et al., 2004). For certain types of cancer surgeries, intensive care unit (ICU) care may be necessary for proper postoperative care. The requirement for ICU care may apply to all surgical procedures for a particular cancer type, or it may be indicated in cases where complications arise during surgery.

OR

Operating rooms (ORs) play a crucial role in the management of cancer patients, as they are responsible for most of the surgical interventions. Depending on the type of cancer surgery, there are various operative approaches, including laparoscopic, robotic, or open surgery. When considering the OR capacity, the scheduling of patients for the OR can be a challenge. Effective OR scheduling is crucial for ensuring efficient access for all patients and adequate operating time for surgeons, thereby promoting success in the OR, surgical practices, hospital, and healthcare (Levine & Dunn, 2015). A common approach for describing the capacity usage is a surgical block, "specific OR and time(s) where designated surgeons or surgical services perform their surgical cases" (Guerriero & Guido, 2011).

Ward

A hospital ward (Wards) is a place with beds for one or more patients who need similar medical care. It helps ensure efficient and effective treatment for patients as they recover. The ward provides a safe and supportive environment for healing, as patients are monitored by the nursing staff and visiting doctors. After most cancer surgeries, patients will be admitted to the hospital ward. For some type of cancers, patient will be admitted to the hospital ward (of a certain specialism) directly after leaving the OR. In other cases, patient will first receive ICU care and will thereafter be transferred to the ICU. Hospital wards are specialised to a certain type of care. Figure 5 shows the metrics used in estimating the ICU, OR and Ward capacity of the hospitals.

Figure 5: Metrics used for the hospital capacity

For the ICU and the Ward this is measured in the average number of days patient are admitted after surgery from a certain cancer type. For the OR this is the average number of hours that a patient is in the OR. For every tumour type there is a different capacity. For every included tumour type, the capacity usage per one surgery is given in Table 4. The amount of time spent in the ICU and OR varies for different types of surgery. Lung and kidney surgeries require less time in the ICU and OR, while pancreas, cervical, and oesophageal tumours need more time. Stomach, liver (primary and secondary), and bladder surgeries fall in the middle with moderate resource usage. The detailed model inputs and the total capacity of the OncoZON hospitals are discussed in Chapter 4.

Tumour type	ICU (Days)	OR (hours)	Ward (days)
Lung	0.28	3	7.36
Pancreas	1.05	5.55	13.44
Kidney	0.05	2.9	2.85
Cervical	0	2.47	5.68
Stomach	0.37	3.09	5.6
Oesophageal	1.5	4.17	9.06
Liver primary	0.4	3.6	5
liver secondary	0.4	3.6	5
Bladder	0.98	4.9	10.33

Table 4: Capacity usage per tumour type for ICU, OR and Ward (retrieved from (Performation Portal, 2023)

Concluding, section 2.1 provides a historical overview of the centralisation of cancer care in the Netherlands, highlighting the ongoing efforts to improve quality and reduce medical errors. The chapter emphasizes the significance of key grey literature, such as the Health Council of the Netherlands' report on the division of tasks in oncology (Van & Zorg, 2020) and from the US Institute of Litt et al. (2000) and Crossing the Quality Chasm (2001) on medical errors and quality improvement. The establishment of organizations like DICA and SONCOS, along with the development of performance indicators and monitoring reports, reflects the commitment to enhancing cancer care standards. 2.2 showed the organisational context, explaining that the problem-owning hospital is the Catherina Hospital Eindhoven, part of the oncology network OncoZON. This section also gives the reasoning for what type of cancer surgery are included in this study, aiming at selecting the tumour types that are included in the 'first wave' of centralisation. The existing volume levels, considered in 2.3, and the anticipated increase in volume norms, underscore the need for collaboration between multiple hospitals to meet the new requirements. 2.4 explains that this study includes ICU, OR and Ward capacity. ICU and OR usage varies for different surgeries, with lung and kidney procedures requiring less time, pancreas, cervical, and oesophageal surgeries requiring more time, and stomach, liver (primary and secondary), and bladder surgeries falling in the middle with moderate capacity resource usage.

Chapter 3: Solution approach

The **solution approach** outlines the research process for the study, including the design and setting. It provides in Section 3.1 a simple overview of the coherence of the different parts of this research. In 3.2 the aim for the literature research is explained. 3.3 focusses on the semi-structured interviews, how they are organised, who is interviewed and why the interviews are conducted. At last, Section 3.4 shows what will be explained in Chapter 4 & 5 regarding the mathematical model and the evaluation framework.

3.1 The research design and research setting

To address the research question, a mixed-methods approach is adopted. The purpose of this approach is to comprehensively understand the subject's complexity by researching it from both qualitative and quantitative perspectives. This research consists of literature research, semi-structured interviews and a mathematical model. The outcomes of the mathematical model are evaluated by an evaluation framework consisting of the most important parameters related to the new allocation of surgeries. Figure 6 shows the different components of the study and how they are related. The dark-blue coloured blocks indicate the four main components of the methods explained in this chapter. The research design was chosen because the mixed-methods approach allows for the use of existing literature to determine a suitable scoring or evaluation framework for the results obtained from the allocation model. Additionally, this framework is discussed with experts from the hospital. This ensures that the outcomes from the model are considered in the context of how they would impact the real world. By incorporating these steps, the research design aims to combine theoretical insights with practical expertise for a comprehensive evaluation of the allocation model's outcomes.

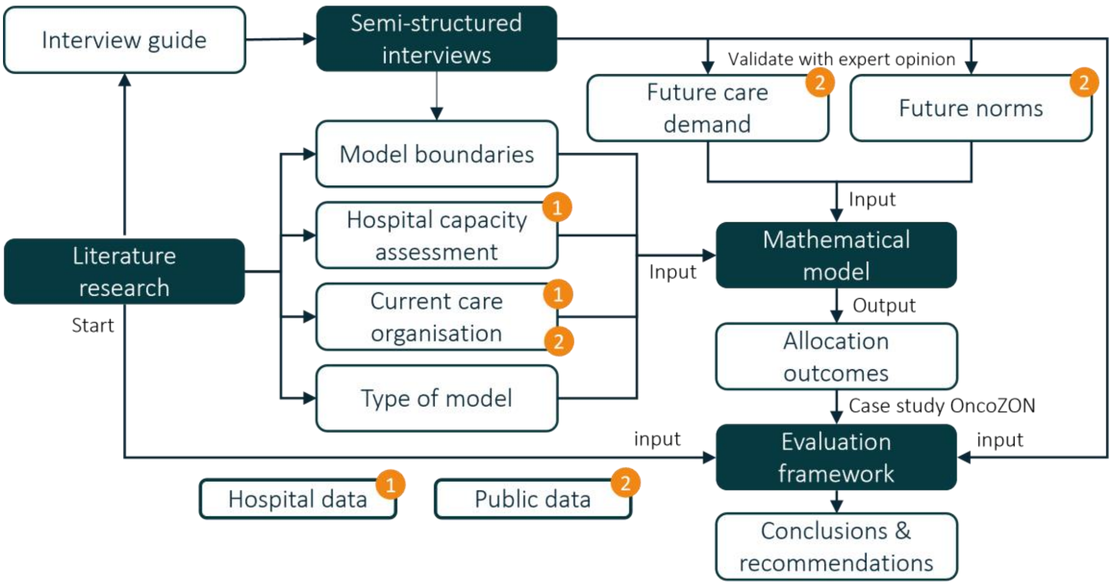

Figure 6: Schematic overview content of the different research parts

3.2 Literature research

The literature research seeks to provide a comprehensive overview of the existing body of knowledge relevant to the research questions. Knowledge production in the healthcare sector is at a high pace, which makes this a useful method for identifying already existing approaches applicable to the problem and identifying the knowledge gaps (Snyder, 2019). This research includes an examination of relevant academic literature on mathematical modelling, as well as an overview of existing grey literature and studies on centralisation in Dutch healthcare. In Chapter 1: Introduction the reasoning was given why the focus of this research is on mathematical modelling. The research focused on exploring relevant literature in the field of mathematical modelling to address healthcare-related problems incorporating uncertainty. Emphasis was placed on techniques such as robust optimisation, stochastic optimisation, and value at risk.

The search for existing reports and studies on centralisation in Dutch healthcare was conducted using a structured approach. The researcher primarily used Google as the search engine of choice, focusing on Dutch keywords such as "Centraliseren van zorg", "Concentreren van zorg" and "Concentratie en spreiding operaties." In addition, specific Dutch research institutes like Nivel, SiRM, and health consultants such as KPMG were targeted to refine the search and locate relevant Dutch reports more effectively. The literature research aims at making an overview of the relevant reports on centralisation, serving as the basis for the development of an evaluation framework to assess the effectiveness of the proposed solutions generated by the research's model. This is done my assessing what affect parameters are named in the reports, and structuring all these parameters across all these reports into one framework for assessing this study's outcomes. In Chapter 5: Evaluation framework the construction and explanation of this evaluation framework is given.

3.3 Semi-structured interviews

Semi-structured interviews are conducted to give depth to the boundary conditions of the model, give organisational insight, and provide a medical perspective to the centralisation questions. The information gathered is used to make statements about potential effects on various parameters later explained in the framework.

Choice of interview type

The reason to use semi-structured interviews as the interview style is that this type of interview gives the freedom to ask relevant follow-up questions. It is valuable to use semi-structured interviews, "If you are examining uncharted territory with unknown but potential momentous issues and your interviewers need maximum latitude to spot useful leads and pursue them" (Adams, 2015). Moreover, conducting one-on-one interviews with the relevant medical professionals ensures that the interviews can concentrate on the specific tumour type in question. Using focus groups may lead to a broad discussion of various medical disciplines, which can compromise the level of detail. It also "ensures that the respondent is unable to receive assistance from others while formulating a response" (Adams, 2015). This is important because if there are other people, doctors or other staff, present, the person answering may not feel free to express their true thoughts and feelings. They might feel pressured to consider other people's opinions and interests, which could affect their responses.

Selection of the interviewees

The selection of the medical professionals for the interviews is done in correspondence with CZE. Following the availability of the specialists it was decided to do a maximum of 4 interviews.

Table 5 shows all interviewees included in this research, and their expertise with regards to the tumour types focused on in this research.

Interview	*Function title*	*Field of expertise relevant to research*
1	Cardiothoracic surgeon	Lung surgery
2	Urologist	Bladder and renal cell surgery
3	Oncologic surgeon	Pancreas, oesophageal and stomach surgery
4	Oncologic surgeon	Oesophageal and stomach surgery

Table 5: All practitioners selected for the semi-structured interviews

Structure of the interviews

For the structure of the interviews, there is a prepared list of topics and questions to guide the conversation. However, the questions asked may be modified or excluded based on the interviewee's responses, and additional questions may be asked as well. Figure 7 shows the overarching topics that are discussed in the interviews. For the three different topics (medical perspective, care demand and future norms, and organizational context), multiple questions have been prepared to guide the discussion and ensure that the topic is covered thoroughly. The complete interview guide can be found in *Appendix B: Topic list & interview script.*

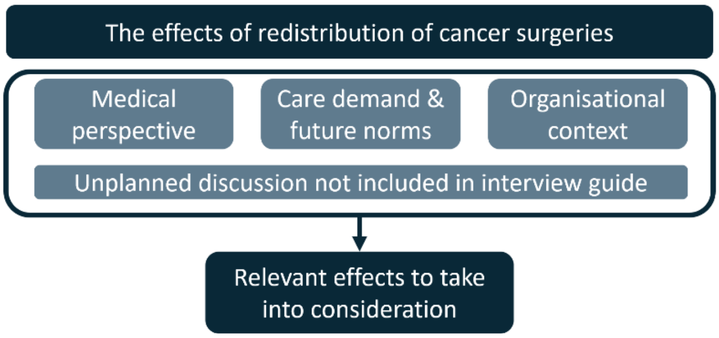

Figure 7: Simplified content of interview guide

Every interview is conducted by the same single interviewer. Next to the interviewee, the doctor, there is always a CZE board delegate present to address any more policy-related questions. For the first interview there was also a senior healthcare consultant from the internship company present to assist the first interviewer and assess whether the interview guide is complete and used as intended. The interviews were, after verbal approval, vocally recorded. This improved the ability for the interviewer to listen closely and ask necessary follow-up questions. It allows the interviewer to be “more actively engaged” instead of having to focus partially on “writing down answers” (Adams, 2015). After the interviews the recording was transcribed and summarized writing down the interviewee's most important statements and insights based on the interview guide's structure. The recordings will be deleted after the finalization of this research.

In conclusion, conducting semi-structured interviews with selected medical professionals provide valuable information regarding the model's boundary conditions, organisational insights, and medical perspectives. These insights contribute to a better understanding of the potential effects on various parameters discussed in Chapter 5: Evaluation framework.

3.4 Mathematical allocation model & allocation framework

Following the literature research and the interviews, a mathematical allocation model and an evaluation framework are proposed. The mathematical model is aimed at allocating surgeries across the OncoZON hospitals. The model has two general objectives: (1) Observing the performance of the model in different norm-scenarios and (2) Providing applicable allocation outcomes for the OncoZON regional case. *Chapter 4: Mathematical allocation model* explains various mathematical models that can be used for this problem, pointing out the advantages and disadvantages of each approach. It then discusses the reasoning for choosing a specific model and provides a description of the chosen model. Finally, a proposed experimental setup is suggested to improve the model's performance when dealing with uncertainty regarding the minimum volume norms.

Next, an evaluation framework is used to assess the quality and impact of the solutions generated by the model. In *Chapter 5: Evaluation framework*, The study incorporates and assesses prominent Dutch reports on the centralisation of care to identify and analyse essential parameters that should be considered when evaluating centralisation efforts. These reports serve as the foundation for constructing the evaluation framework in the study, enabling a comparison of different model outcomes.

Concluding, Section 3.1 provides the solution approach for addressing the research question. A mixed-methods approach, combining qualitative and quantitative methods, is adopted to comprehensively understand the complexity of the subject. The research design consists of literature research, semi-structured interviews, and a mathematical allocation model. The literature research (3.2) aims to identify existing approaches and knowledge gaps related to mathematical modelling and centralisation in Dutch healthcare. Semi-structured interviews in 3.3 with four medical professionals provide valuable insights into the model's boundary conditions, organizational context, and medical perspectives, using an interview guide to structure the interviews. 3.4 also introduces the mathematical allocation model, which aims to allocate surgeries across the OncoZON hospitals, and an evaluation framework to assess the quality and impact of the model's outcomes. Overall, this approach combines theoretical insights from literature research with practical expertise from interviews to provide a comprehensive evaluation of the allocation model's effectiveness in the real-world context.

Chapter 4: Mathematical allocation model

The **mathematical allocation model** explores relevant literature on hospital resource allocation and presents the selected model for addressing the allocation problem. Section 4.1 examines single and multiple hospital allocation models, providing justification for the chosen approach. The model description is presented in Section 4.2, outlining its functionality. Section 4.3 discusses the calculation and explanation of model inputs, while Section 4.4 outlines the experimental methodology used.

4.1 Literature regarding hospital resource allocation models

In this research, the goal is to make decisions on where to allocate which type of cancer surgery. Following the hierarchical decomposition of Hans et al. (2012) the allocation problem is on a strategic level. It embodies the structural decision on which hospital will be providing what surgical care, which has cascading effects on the hospitals' direction and strategy. To offer an overview of the existing scientific literature on resource allocation in single and multiple hospitals, this review discusses several interesting articles that provide valuable insights into this subject.

Single-hospital resource modelling

Regarding (resource) capacity planning, a great amount of hospital capacity models are focussed on assessment for one specific hospital. (Burdett et al., 2017) proposed a mixed integer linear programming approach to perform hospital capacity assessments. This research focussed on what the theoretical performance of the hospital could be in terms of capacity. The methodology by Burdett et al. (2017) establishes an upper limit for a hospital's productivity and ability to deliver care. Wang et al. (2016) developed a multi-objective optimiser for three control factors: bed distribution among wards, overflow threshold (patients assigned to wards not best suited for their primary condition), and discharge distribution. Bai et al. (2019) looked at how to allocate surgical capacity strategically while taking into account surgeon preferences and OR sharing. Their methodological framework can assist OR managers in choosing a surgical capacity allocation that is highly predictable, which enhances OR utilisation and patient safety and makes it easier to schedule perioperative staff members consistently. For the capacity of the OR, they predetermined a fixed amount of available hours, and also the acceptable exceedance in the form of overtime. They identified "surgeon pairs" (sharing ORs) associated with low overtime probability and expected overtime using a data-driven approach described in Wisittipanich et al. (2021).

Samanlioglu (2013) used a mathematical programming model to resolve the multi-period surgical scheduling problem. The weighted sum approach was used to formulate the scheduling problem as a multi-objective model with two objectives: minimization of makespan and minimization of the total least preference assignment score. This model demonstrated its superiority in terms of computational efficiency and will be used going forward as a clever decision-making tool in the scheduling of hospitals. This problem was discussed in this study under the presumption that the capacity and duration of the surgeries are deterministic variables and that only non-pre-emptive cases are taken into consideration. More likely, the arrival of urgent or emergency surgeries could happen and force preemptions in the schedule. As a result, more studies should concentrate on stochastic modelling to manage uncertainty in practical applications.

In summary, these studies highlight the significance of capacity planning and scheduling in hospitals. While Burdett et al (2017)., Wang et al. (2016), and Bai et al. (2019) propose models and frameworks for assessing capacity, optimizing resource allocation, and considering surgeon preferences, Samanlioglu (2013) mathematical programming model offers computational efficiency for surgical scheduling.

Multi-hospital resource modelling

Research on multiple locations are mostly focussed on the allocation of hospitals or care units Itself. Ikkersheim et al. (2013) aimed at providing a model to evaluate the Dutch hospital infrastructure by optimizing quality, accessibility and efficiency via a mixed integer programming model. This research looked at the total curative care and the potential health benefits of changing the number of hospitals. Their model showed that complex and acute care may be too dispersed in the Netherlands. Luo & Cai (2016) addressed a surgery capacity sharing problem with multiple hospitals. Each hospital does have a random demand, and is in need for sufficient capacity to accommodate the surgeries. The proposed model includes the capacity of all hospitals and corresponding (potential) profit when providing capacity for another hospital. The objective of the model is to maximize the total expected profit.

Using a coalition of different hospitals in a strategic network, Roshanaei et al. (2017) expanded the scope of the OR planning and scheduling problem from a single independent hospital to include a pool of patients, surgeons, and ORs. According to this study, the success of a surgery depends on the availability of two resources: surgeons and operating rooms. Since surgeons in this scenario are free to move between cooperating hospitals on different days of the week, the model assigns surgeons to hospital-days.

In general, research on multiple location modelling has primarily focused on the allocation of hospitals or care units. Through various optimisation models, these studies have highlighted the need for efficient allocation of resources and strategic collaboration between hospitals to improve patient outcomes. Specifically, the studies demonstrate that a careful balance between quality, accessibility, and efficiency is necessary to provide effective care. The studies also highlight the complexity of most healthcare systems, with one major reason being the fact that uncertainty in decision-making processes is challenging (Otten et al., 2023). *This research* is also complexified by the fact that the "minimal" volume norms for hospitals are uncertain, and changes in which tumour types will have and what height of norms can significantly impact modelling outcomes.

Modelling uncertainty

In strategic level optimisation problems, the data used often entails uncertainty, as it is not precisely known at the time of problem-solving. This is particularly relevant in the context of this research, where the precise care demand and future volume norms remain unknown and can only be estimated to a certain extent. Following Ben-Tal et al. (2009) the reasons for data uncertainty include:

- *Measurement/estimation errors* coming from the impossibility to measure or estimate precisely the data entries representing characteristics of the system.
- *Implementation errors* coming from the impossibility to implement a solution exactly as it is computed. The solution provided — input to a system, resource allocation etc. — they clearly cannot be implemented with the same high precision to which they are computed.

In many cases, the uncertainty is simply ignored during the stage of building the model. When finding an optimal solution, uncertain or unknown data is estimated with some values, and the some care of uncertainty (if any) is taken by sensitivity analysis afterwards. This is a post optimisation tool allowing just to analyse the stability properties of the already generated solution (Ben-Tal & Nemirovski, 1998). In short, sensitivity analysis does not change the solution of the optimisation problem, it only examines how the optimal solution changes when the input data changes.

Uncertainty is a common challenge in optimization problems, and two techniques for addressing this issue are stochastic programming (SP) and robust optimization (RO). While both methods aim to handle uncertainty, they differ in their approaches and outcomes.

Stochastic programming (SP) is a modelling technique that deals with uncertainty by incorporating probability distributions. It assumes that the underlying uncertainty is stochastic in nature and requires knowledge of the probability distributions (Ben-Tal & Nemirovski, 1998). In SP, the uncertainty is typically represented by a set of scenarios or a probability distribution. The objective is to optimize the decision variables such that the expected value of the objective function is minimized or maximized, considering the uncertainties. SP allows for the incorporation of stochastic constraints, which are constraints that must be satisfied on average across the scenarios.

Robust optimisation (RO) is a mathematical optimisation technique that aims to deal with a certain measure of robustness against uncertainty in the data. Following this approach, only specific sets in function space—the so-called "uncertainty sets"—are assumed to contain the objective and constraint functions. The objective is to find a solution that is both optimal for the worst-case objective function and realisable under any set of constraints (Ahmadi & Hall, 2012). In other words, RO is able to deal with uncertainty in the hard constraints, i.e., those which must be satisfied within the ranges of the uncertainty set (Ben-Tal & Nemirovski, 1999). A robust approach's quality is determined by how expensive it is to continue to be feasible despite changing parameter values. The cost of a robust solution is determined by assessing a trade-off between the robustness and the ideal objective value, which is attributed to potential over-conservatism (Aslani et al., 2019).

One of the main advantages of RO over SP is that it provides a more reliable performance guarantee. In SO the performance of the system is only guaranteed on average, and there is a non-zero probability of the system performing poorly. In contrast, RO guarantees that the system will perform well even in the presence of uncertainty (Kazemzadeh et al., 2019). On the other hand, an advantage of SP over RO lies in its ability to generate less conservative solutions. While RO focuses on worst-case scenarios and ensures system performance under uncertainty, SP embraces the stochastic nature of the problem and allows for more flexible and potentially more efficient solutions (Roos & Hertog, 2020).

Another advantage of RO is that it is less sensitive to the distribution of the input data. As stated earlier, In SP, the performance of the system is heavily dependent on the assumptions made about the distribution of the input data. In contrast, RO does not rely on such assumptions and therefore is more robust to changes in the input data. SP can lead to solutions that are highly sensitive to small changes in the input data, which can lead to large changes in the performance of the system (ProfoundQa, 2022). Denton et al. (2010) aimed to find the best distribution of surgery blocks across operating theatres, and they made the robust counterpart of the model with the aim of minimising the maximum cost associated with an uncertainty set for surgery durations. Through numerical experiments, they discovered that the robust method works much more quickly than solving the stochastic resource model. Additionally, the robust method outperformed the heuristic fairly well and has the advantage of limiting the worst-case scenarios for the recourse problem. In general It could be said, SP is aimed at answering a completely different question: How does the solution of an optimisation problem changes as input parameters are varied? While RO focusses on the question: How do you built an uncertainty-immunized solution to an optimisation problem with uncertain data? (Ben-Tal et al., 2009).

Due to insufficient data, many healthcare providers often face challenges in calibrating SP models. RO models, by contrast, can effectively account for uncertainty in model inputs. Denton et al. (2010) tried to account for the uncertain surgery times affecting the surgery scheduling and Gökalp et al. (2020) incorporated a robust optimisation-based approximation of the maximum waiting time in the donation search process. Motallebi Nasrabadi et al. (2020) incorporated demographic variation in health care demand for capacity planning of public healthcare facilities and Breuer et al. (2022) addressed uncertainty in patient volumes to optimize care access.

RO models are criticised in literature for producing excessively conservative solutions because they aim to optimise for the worst-case scenario of the uncertain parameters. The conservatism of RO solutions has been the subject of numerous studies. When a multi-stage problem is taken into consideration using adjustable/adaptive RO (ARO), for instance, the uncertainty set and the associated robust solution are updated each time an observation of uncertainty is made (Ben-Tal et al., 2004). Studies have attempted to make these models more tractable under specific circumstances because these ARO models are frequently computationally difficult (Ardestani-Jaafari & Delage, 2018; Bertsimas & Caramanis, 2010; Bertsimas & Goyal, 2013). These research findings emphasize the significance of reducing the degree of conservativeness in various types of RO models. Addis et al., (2014) proposed a *cardinality-constrained RO* approach for operation room planning, which manages over-conservatism using a polyhedral uncertainty set. By defining a budget of uncertainty, the decision-maker can control the level of conservatism within the permissible range of cardinality.

Model choice for this research

The most important challenge is how to model uncertainty regarding the norms for every tumour type. Robust optimisation is suitable to perform well against uncertainty with high impact on the outcomes (Bertsimas et al., 2007). Starting with worst-case realisations of all norms could be a suitable initial approach to provide a sound solution. However, as pointed out by Bertsimas & Sim (2004), a full-robust optimisation approach may be too conservative for this specific problem, given that it is unlikely that all norms will reach their maximum value. To overcome this overconservativeness, an option would be to look at a *cardinality-constrained approach*, where you restrict the number of uncertain coefficients in a constraint that can vary from their nominal value by a parameter, the so-called budget of uncertainty (Filabadi & Mahmoudzadeh, 2022). But, in the context of the uncertainty around the cancer norms, a *cardinality constrained approach* with a budget of uncertainty may not be a suitable solution. Since each tumour type has only one worst-case value for its corresponding constraint, using this approach would cause all norms to reach their maximum value, resulting again in a full robust outcome. Therefore, it is more effective to focus on a combination of tumour types, some of which experience worst-case values and some that do not. The approach could be similar to Blanco & Morales (2017) model for power systems. Here, a large number of scenarios is considered and these are grouped in so called partitions. The number of partitions considered then controls the level of conservativeness.

An alternative approach is stochastic programming, but this may not be a suitable solution as it needs a probability distribution for the uncertainty (Kazemzadeh et al., 2019). The lack of knowledge about which specific combination of norms will reach their maximum value makes it difficult to estimate the probability of different outcomes. Instead, the uncertainty stems from the lack of knowledge about which specific combination of norms will reach their maximum value, rather than a probabilistic distribution for the values of each norm.

Another option could be to work with some form of Value-at-Risk or Conditional-Value-At-Risk modelling to quantify potential loss at or beyond a certain cut-off point (Gourieroux & Jasiak, 2010). In this case, the focus is on quantifying the potential loss in worse-case norm realisations. The problem is that there is no recourse to take into account. Since the decision on how to allocate surgeries must be made before the norms are determined, and once the norms are set, there is no possibility for recourse or adjustment. This makes it difficult to quantify the consequences of certain allocation decisions in terms of the ‘value-at-risk’.

The model proposed in this research incorporates the idea of robust optimisation, and aims at overcoming over-conservatives by varying the number of norm combinations it takes into account. It formulates the following two modelling approaches, leading to a '*scenario-robustness approach'*:

- *Robust optimisation approach* – Focuses on the best outcome when all norms take their 'worst-case value'.
- *Scenario-robustness approach* – Focuses on improving outcomes when a selection, but not all, of the norms take extreme values. Thus improving cases when a selection of worst-case norm-scenarios occur.

Initially, there was a deterministic start model made, this model used the average expected norms per tumour type as values for the minimal value norms. This model can be found in *Appendix C.1: Deterministic model*. Next, to assess the outcomes for the robust optimisation approach in the situation where all norms will have their 'worst-case value' the box-uncertainty approach is used. Next, the box uncertainty approach is used to construct a fully robust model that takes into account the potential range of norms for each tumour type. In this approach, the "worst-case" scenario is identified, wherein the deviation from the average expected norms is maximally positive. As a result, a deterministic model is developed, with the norms' values set to their maximum possible value. *Appendix C.2: full robust model* shows this full robust model that was constructed using the box uncertainty approach.

The model that is shown below is the final model that is used for the *scenario-robustness approach*. In this model, multiple norm-scenario's are taken into account. This approach aims to improve outcomes when only certain norms exhibit extreme values, specifically targeting scenarios where a selection of worst-case norm-scenarios occur.

4.2 Model description

This section contains the model description with the sets, parameters, decision variables. It also explains the objective of this model together with the constraints. The experiment approach will be explained in Section 4.4 Experiment set-up.

Sets

SurgTypes	The surgery tumour types	With index **t**
Hospitals	The OncoZON hospitals	With index **h**
Capacities	The capacity types (ICU, OR and Ward)	With index **c**
Scenarios	The norm scenarios	With index **k**

Parameters

Demand (t)	Total demand for tumour type **t**
Norms (k,t)	The minimal volume norm for tumour type **t** in scenario **k**
CapHosp (h,c)	The total capacity of hospital **h** of capacity **c**
Cap(t,c)	The amount of capacity **c** used for one surgery of type **t**
CurrSurg (t,h)	The current number of surgeries of type **t** at hospital **h**
BigM	A large, positive number (1000)
OpenNow(t,h)	1, if hospital **h** is performing surgeries of type **t** currently (CurrSurg[t,h] > 0); 0, otherwise
WeightCap(c)	The penalty cost for extra capacity of type **c**

Decision variables

AllocatedSurg (t,h)	Number of surgeries of type **t** assigned to hospital **h**
OpenOrNot (t,h)	1, if hospital **h** is assigned to perform surgeries of type **t;** 0, otherwise
CareShifts[t,h]	Auxiliary variable for linearization of the absolute value of AllocatedSurg[t,h]-CurrSurg[t,h]
CapExtra[h,c)	The amount of extra capacity used at hospital **h** of capacity type **c**

The model

$$\textbf{minimize} \quad \sum_t \sum_h CareShifts_{t,h} + \sum_h \sum_c (CapExtra_{h,c} * WeightCap_c) \quad [1]$$

Subject to

$$AllocatedSurg_{t,h} - CurrSurg_{t,h} \leq CareShifts_{t,h} \quad \forall(t,h) \quad [2]$$

$$-CareShifts_{t,h} \leq AllocatedSurg_{t,h} - CurrSurg_{t,h} \quad \forall(t,h) \quad [3]$$

$$\sum_h AllocatedSurg_{t,h} \geq Demand_t \quad \forall(t) \quad [4]$$

$$\sum_t (AllocatedSurg_{t,h} * Cap_{t,h,c}) \leq CapHosp_{h,c} + CapExtra_{h,c} \quad \forall(h,c) \quad [5]$$

$$AllocatedSurg_{t,h} \leq BigM * OpenOrNot_{t,h} \quad \forall(t,h) \quad [6]$$

$$AllocatedSurg_{t,h} + (1 - OpenOrNot_{t,h}) * BigM \geq Norms_{k,t} \quad \forall(t,h,k) \quad [7]$$

$$OpenNow_{t,h} \geq OpenOrNot_{t,h} \quad \forall(t,h) \quad [8]$$

$$AllocatedSurg_{t,h}, CareShifts_{t,h}, CapExtra_{h,c} \geq 0$$

$$OpenOrNot_{t,h}, \in \{0,1\}$$

The objective function [1] corresponds to minimizing the care shifts and extra capacity. Because the different types of capacity have different metrics, the $WeightCap_c$ ensures that their contributions the objective is the same. The current surgery allocation is subtracted from the new allocation giving the absolute surgeries shifts. Constraints [2] and [3] ensure that the absolute value of this subtraction is realized. The allocation decision is further constrained by [4], the fact that the total surgery demand per type should be met. [5] is a soft constraint ensuring that the total capacity resources used is not exceeding the available capacity. The extra capacity is penalized in the objective function. Constraints [6] and [7] make sure that the minimum volume norms are met, in other words, it forces a hospital that provides a certain tumour type to meet the minimum volume norm of that type. $Norms_{k,t}$ in constraint [7] represents the norms per tumour type and scenario. For experimenting, the range of the index **k** can be changed so that only a limited subset of norm scenarios are constrained. At last, [8] ensures that hospitals are not assigned tumour types when they are not providing this type of care in the current situation.

4.3 Model inputs

Future total surgical demand ($\boldsymbol{Demand_t}$)

The trend report published by IKNL (2022) provides a starting point for estimating future surgical demand. As the report covers cancer incidence, mortality, prevalence, and survival for the entire Netherlands, the development of crude incidence rates between 2019-2022 are compared for the entire Netherlands to those of the combined regions of Noord-Brabant and Limburg (OncoZON region) to understand their similarity. The 2024 total OncoZON demand from the current 2021 volumes are then estimated using expected national growth rates. The calculation process is explained in detail in *Appendix D: Estimation of the total care demand*. The incidence rates for the different tumour types considered in this research are derived from the IKNL trend report (2022) and the Dutch cancer registry data (*NKR Cijfers | Incidentie - Grafiek*, 2023).

Tumour type	*Incidence % Δ 2019-2022 Netherlands*	*Incidence % Δ 2019-2022 Noord-Brabant+Limburg*	*% point Δ B+L to NL*
Lung	7.41	5.17	-2.24
Pancreas	7.55	7.72	0.17
Kidney	0.58	-0.80	-1.38
Cervical	12.41	-0.94	-13.35
Stomach	-9.05	-6.97	2.08
Oesophageal	1.16	-1.89	-3.05
Liver primary	26.49	18.10	-8.39
liver secondary	26.49	18.10	-8.39
Bladder	3.66	7.43	3.77

Table 6: Comparison of incidence rates of the Netherlands and Brabant+Limburg region

Table 6 shows the percentage change of the incidence of both the Netherlands and the regions Noord-Brabant and Limburg combined. The last columns show the percentage point difference between these incidences. The incidence trend from Noord-Brabant and Limburg are predominantly similar to the national average. However, for tumour types liver (both types) and cervical, this is less the case. This is an important factor to take into account for the sensitivity analysis.

Tumour type	*Annual growth '19 -'27*	*Annual growth '22-'27*	*Annual growth '19 -'27 adjusted*	*Annual growth '22-'27 adjusted*
Lung	***1.59***	***1.35***	***1.02***	***1.01***
Pancreas	3.07	2.66	1.03	1.03
Kidney	2.59	2.10	1.03	1.02
Cervical	-2.00	-0.26	0.98	1.00
Stomach	-1.29	-0.81	0.99	0.99
Oesophageal	2.36	2.16	1.02	1.02
Liver primary	4.57	3.74	1.05	1.04
liver secondary	4.57	3.74	.1.05	1.04
Bladder	1.31	1.18	1.01	1.01

Table 7: The growth in incidence in terms of yearly increase

Using nationwide growth rates obtained from (IKNL, 2022) for over a 5-year period, the yearly increase or decrease is calculated and shown in Table 7. The grow rates are used to estimate the volume of the tumour types for the year 2024, based on the current numbers from 2021. The total surgical demand for OncoZON in 2021 and 2024 is shown below in Table 8. The division in 2021 per hospital is already shown in Section *2.3 Current norms.*

Tumour type	*Current demand 2021*	*Estimated demand 2024*
Lung	251	262
Pancreas	92	97
Kidney	301	322
Cervical	62	60
Stomach	54	52
Oesophageal	82	88
Liver primary	176	198
liver secondary	157	177
Bladder	147	152

Table 8: Total surgery demand for OncoZON in 2021 and 2024

Hospital capacity

The hospital capacity is divided into three types: ICU, OR and Ward. CZE has provided the average utilization of capacity for each of these categories for all tumour types. These averages are derived from a benchmarking tool (*Performation Portal*, 2023) that allows hospitals to assess their capacity relative to the average. Table 9 displays the average capacity usage and the total capacity for each hospital. The total capacity is calculated by multiplying the current surgical volumes with the corresponding average capacity usage.

Tumour type	*ICU (Days)*	*OR (hours)*	*Ward (days)*	*Hospital*	*Total IC (Days)*	*Total OR (hours)*	*Total Ward (Days)*
Lung	0.28	3	7.36	Anna	231.45	1506.51	2944.69
Pancreas	1.05	5.55	13.44	CZE	0.00	2.41	5.54
Kidney	0.05	2.9	2.85	Elkerliek	0.21	19.63	28.81
Cervical	0	2.47	5.68	Laurentius	65.86	694.47	1062.11
Stomach	0.37	3.09	5.6	MUMC	188.78	1557.12	2665.91
Oesophageal	1.5	4.17	9.06	MMC	14.72	220.84	431.96
Liver primary	0.4	3.6	5	SJG	0.00	2.41	5.54
liver secondary	0.4	3.6	5	VieCuri	23.86	254.90	373.78
Bladder	0.98	4.9	10.33	Zuyderland	116.21	770.61	1506.01

Table 9: Capacity usage for all types and total available capacity per hospital

Minimum volume norms

From IZA (van Volksgezondheid & Sport, 2022) it is known that the norms per type will be increased to either 50 or 100 per hospital location per year unless there is scientific evidence that this is not desirable. For cervical surgeries, there are different minimum and maximum volumes due to lower total surgery demand, as a result of recent vaccination rounds (*2+ Million Invitations to Get Vaccinated against HPV in 2023 | RIVM*, 2022). For pancreas, stomach and oesophageal surgeries it is also already known that the volume norm will be set to 50. This information is checked with expert opinion during the interviews. Table 10 shows the overview of the norm min and max values for all types. It also shows the current norms.

Tumour type	*Current norm*	*Min value new norm*	*Max value new norm*
Lung	20	50	100
Pancreas	20	50	50
Kidney	10	50	100
Cervical	20	20	50
Stomach	20	50	50
Oesophageal	20	50	50
Liver primary	20	50	100
Liver secondary	20	50	100
Bladder	20	50	100

Table 10: The current norms and the minimal and maximum expected norms per tumour type

4.4 Experiment set-up

Experiments for all norm scenarios

The goal is to make the allocation solution from the mixed-integer programming (MIP) model robust against a varying number of norm combinations. In other words, the aim is to explore how the solutions change when there is a different combination of norm values enforced.

First, the following experiments are conducted:

1. All norms are set to their maximum values. Full robust MIP model is solved, this results in 1 model outcome.
2. All norms are set to their minimum values. The deterministic MIP model is solved, this results in 1 model outcome.
3. 1 out of 6 tumour types norms will be set to their maximum value, and the rest will be set to their minimum values. The deterministic MIP model is solved for all norm combinations, this results in 6 model outcomes.
4. 2 out of 6 tumour types norms will be set to their maximum value, and the rest will be set to their minimum values. The deterministic MIP model is solved for all norm combinations, this results in 15 model outcomes.
5. 3 out of 6 tumour types norms will be set to their maximum value, and the rest will be set to their minimum values. The deterministic MIP model is solved for all norm combinations, this results in 20 model outcomes.

Scenario-robust approach

After these initial experiments, the outcomes are stored separately for each of the combinatory experiments 3-5. These outcomes are then sorted based on their objective function value, allowing for the identification of the norm combinations that resulted in the worst outcomes. These outcomes are then stored in $\boldsymbol{Norms_{k,t}}$.

Using this information, the final model is solved again with an increasing number of enforced norm scenarios, based on the stored outcomes. This is achieved by gradually changing the index **k**, as summarized in Table 11. This scenario-robust approach ensures that the norms that resulted in the worst outcomes are taken into account first, leading to a more robust solution.

Experiment number	*Experiment name*	*Index k varied between (= number of scenarios included in the model)*
1	All max	1
2	All min	1
3	1 out of 6	1 to 6
4	2 out of 6	1 to 15
5	3 out of 6	1 to 20

Table 11: The ranges of index k for the different experiments

Concluding, Section 4.1 reviews the resource allocation in healthcare, both in single and multiple hospital settings and has provided valuable insights. Single-hospital studies focused on capacity planning, resource allocation optimization, surgeon preferences, and surgical scheduling. Multi-hospital research emphasized the allocation of hospitals or care units and the importance of strategic collaboration for improving quality, accessibility, and efficiency. These studies highlight the complexity of healthcare systems and the challenges posed by uncertainty, particularly in the context of changing norms for cancer surgeries.

The model used in this research adopts a scenario-robustness approach, combining robust optimization and varying norm combinations. Initially, a deterministic model based on average expected norms was developed. Instead of considering all norms at their worst-case values, which could be overly conservative, the scenario-robustness approach targets specific worst-case norm scenarios to improve outcomes. Stochastic programming and Value-at-Risk modelling were not suitable due to the lack of knowledge about specific norm combinations and the absence of recourse.

The final model presented in 4.2 addresses uncertainty in cancer norms and enhances resource allocation decision-making. The model minimizes care shifts and extra capacity while allocating different surgery types across hospitals. It considers penalties for care shifts and extra capacity, with weights ensuring fairness among different capacity types. The input for the model, in 4.3, includes the future total surgical demand estimate based on a trend report, incidence rates for different tumour types, and growth rates. Hospital capacity is divided into ICU, OR, and Ward, with utilization averages provided. Minimum volume norms per tumour type are specified, with expected increases to either 50 or 100 per hospital location per year. 4.4 explains that the experiments aim to test different combinations of norm values to see how the allocation solution holds up. It starts with extreme scenarios where all norms are set to their maximum or minimum values. Then, specific tumour type norms are gradually varied while others remain constant. The outcomes are recorded and sorted based on their objective function values. Using this information, the model is run again, gradually including the norm combinations that resulted in the worst outcomes. This approach ensures the model tackles the toughest norm scenarios first, leading to a more robust solution.

Chapter 5: Evaluation framework

The **evaluation framework** Section 5.1 explores reports on centralisation, highlighting its impact and considerations. Section 5.2 introduces an evaluation framework to assess outcomes within OncoZON, emphasizing the need for structured evaluation. In Section 5.3, a Likert scale is proposed for scoring the model outcomes based on expert interviews. This standardized scoring system aims to provide transparency and assess perspectives from patients, the hospital system, and the medical profession.

5.1 Reports on centralisation

To better interpret the results of the mathematical modelling in the healthcare setting, it is important to examine how similar centralisation problems have been evaluated in the past. In the Netherlands, the topic of centralising care has been widely discussed and studied, and by looking at earlier reports, it gains valuable insights to help understand the outcomes of the model.

General reports on centralisation

Nivel, a public organisation conducting healthcare research, published a report to provide a broader perspective on centralisation. Regarding minimum volume norms, they state that "The policy discussion should focus on what form of organisation and mode of care delivery optimises quality, rather than focusing unilaterally on the presence of a sufficient number of patients" (Zuiderent-Jerak et al., 2012). Their report aimed to look critically at an unambiguous relationship between volume and quality of care. They claim that whereas in the discussion on centralisation of care, the importance of quality gains for patients is underlined, in practice the definition of this appears to be filled in mainly from an organisational and professional point of view.

Honing & Marres (2012) write that specialists should take the lead in setting quality standards and volume requirements for oncology centres. The report emphasizes the significance of collaboration among diverse stakeholders, such as medical specialists, policymakers, and healthcare insurers, in implementing successful strategies for centralising cancer care. If the shared-decision making is lacking, the government could make volume-increase decisions without sufficient support. This type of decision-making can now be seen in the centralisation of paediatric cardiac surgery, leading to huge difficulties for a constructive organisation (De Jonge, 2021). It shows that a sole focus on volumes from a merely theoretical point of view is not sufficient to arrange support from organisations.

Case reports

KPMG (2018), commissioned by the Dutch Healthcare Institute, examined the implications of the centralisation of emergency care, and the possible cascade effects. In this case, 'cascade effects' are the (unintended) effects that can occur in a hospital that does not provide certain emergency care after centralisation. They propose an analytical framework for the possible cascade effects. This framework is then used by them as a guide in preparing the questionnaire for the interviews. Their framework consists of four blocks: (1) Quality and volume of the relevant urgent care indication, (2) Quality and volume of other urgent care, (3) Quality and volume of adjacent non-urgent care, and (4) Profitability of the 'leaving' hospital (with possible effects on all care). Each of the four blocks consists of possible sub-effects. The report used the framework to evaluate and weigh the different possible centralisations and elaborate on the cascading effects (KPMG, 2018)

The Dutch Healthcare Authority (NZa) conducted an impact analysis on the centralisation of interventions for patients with congenital heart defect (AHA). They examined the impact for patients, healthcare professionals, healthcare organisations, training education & research and society. From the patient perspective, a questionnaire was conducted to give insight into the reasons why patients are adverse to (further) centralisation of AHA. The most frequent reasons: (1) Preference for trusted, familiar doctor, (2) The believe that all care will be concentrated, (3) Increase of travel time, (4) Fear of quality decrease, and (5) Preference for all care in one location. From the healthcare professional perspective, they distinguish between the consequences for the medical specialists performing the interventions, nurses and the other healthcare professionals involved. The most important effects in general is the uncertainty of future work and its location. In addition, after making the decision to further concentrate the AHA care, possible cascade include: (1) Departure of medical specialists abroad and (2) Current AHA specialists in training exceed (future concentrated) demand for care. Next, the report focusses on the implications for regional cooperation. They pinpoint to properly organise care for all patients, good cooperation should be sought between intervention sites, shared care sites and local hospitals for shaping the pre- and postoperative process close to the patient's home. At last, the financial impact is discussed. Centralising AHA interventions has financial implications for the intervention centres involved. Important financial parameters to consider are: production-revenue and financial implication for educational funds. In this case, the expectation is that the financial effects of moving the operations and cardiac catheterisations are (very) limited compared to the total turnover of the hospitals. This is also mitigated by the fact that freed up capacity could possibly be used for other care (NZa, 2022).

As briefly described in the introduction, SIRM conducted research (de Haas et al., 2020b) on the possible death prevention potential of (further) centralisation with respect to the travel time of patients. For an additional twenty minutes of typical travel time, eight additional complex non-acute operations might avoid about sixty deaths. Six of these surgeries were oncology surgeries. They even went further and claimed that since there are many other actions for which centralisation may be advantageous, the overall impact of centralisation would be up to 200 prevented fatalities.

5.2 Construction evaluation framework

To evaluate the outcomes of the mathematical model, and thus the new possible allocations, an evaluation framework is developed. This framework aims at providing an overview of the possible future scenarios within OncoZON and their corresponding organizational effects. It should be noted that there is a possibility of confirmation bias in the evaluation process due to the personal interests of hospital staff. To mitigate this bias, the framework is designed to evaluate all scenarios in a consistent manner, based on predetermined criteria, and using a transparent comparable system.

The aim of the framework is to ensure that not only the direct results of changes are evaluated, but also the potential cascade effects. These effects may not be easily anticipated by solely examining the changes in volume, but can be better accounted for through the structured evaluation approach offered by the framework. In addition, it makes sure that this problem is not only viewed from an organisational perspective, but also from the patient and staff, which should be a critical aspect for future decision-making.

Nine reports were included in the review because they closely examined the centralization of care in the Dutch healthcare system, which shares similarities with the problem addressed in this study. These reports investigated different forms of centralization, providing valuable insights for understanding the outcomes of the research. Other reports that did not align with the Dutch healthcare system or the centralization of care were not included.

Table 12 shows for the nine reports which effect/parameter was studied and it across all reports overlapping studies parameters. For these reports both the aim of the research, together will all the parameters discussed are written down and summarized (see *Appendix E: Study basis for the evaluation* framework). To provide a clear overview, the effects are divided into three perspectives, those of the patient, the hospital system and the medical profession. In practice, of course, effects cannot be definitively categorized into a single group, but this approach gives more structure to evaluate the outcomes of the model. This information is merged into one framework, shown in Figure 8.

Effect group	Parameter name	Effect studied	(KPMG, 2018)	(Zuiderent-Jerak et al., 2012)	(Wijsman, 2013)	(van den Berg et al., 2021)	(Honing & Marres, 2012)	(MedischContact, 2012)	(K&Z & VSOP, 2016)	(de Haas et al., 2020)	(Nederlandse Zorgautoriteit, 2022)
Patient	Travel time	Travel time of a patient	X	X				X	X	X	X
	Waiting time	Waiting time patient		X					X		
	Freedom of choice	Freedom of (hospital) choice		X					X		
	Quality of surgery	Quality of care – WRT volume	X	X			X	X	X		
	Integral care pathway	Care at one location		X				X	X		X
Hospital system	Resource usage	Usage equipment / rooms hospital	X								X
	Revenue implications	Financial implications	X	X			X	X		X	X
	Portfolio – care volume	Amount of surgeries of certain type	X			X					
	Portfolio – care type	Type of surgeries			X	X		X			
	Sustainability	Strategic position hospital		X	X			X			
Medical profession	Composition	Staff composition	X	X		X		X			X
	Academic research	Academic research in certain medical field					X			X	
	(Re)training and education	Staff/specialist (re)training, education		X		X					X

Table 12: Studies included for selection of all relevant parameters of evaluation framework

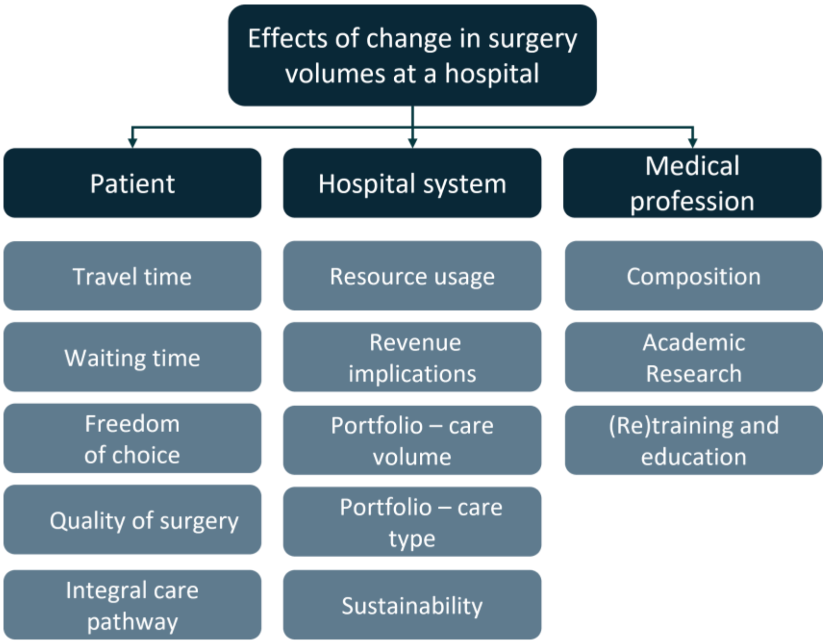

Figure 8: *Schematic overview of the framework of the possible effects of redistribution of surgeries*

For all the parameters, the effects on the patient, hospital system and medical profession are further explained in Table 13, Table 14 and Table 15 below. In addition, it is explained how the parameters are assessed (assessment) and what the question is that is aimed to be answered (scope). The proposed perspectives in the framework offer a broader understanding of the implications per viewpoint as a result of changing surgery volumes.

Effects on patient level

Metric	*Assessment*	*Scope*
Travel time	Qualitative	What are the implications for travel time when the number of locations providing surgery decreases?
Waiting time	Qualitative	Is it expected that the centralisations lead to more efficient care?
Freedom of choice	Qualitative & quantitative	How does the number of hospitals providing certain surgeries affect the freedom to choose a hospital?
Quality of surgery	Qualitative	What is the expectation regarding the decrease in mortality?
Integral care pathway	Qualitative	What are the changes in referrals between hospitals?

Table 13: The parameter metrics, assessment and scope from patient perspective

Effects on hospital system

Metric	*Assessment*	*Scope*
Resource usage	*Qualitative & quantitative*	What are the Implications for the usage of IC, OR and Ward?
Revenue implications	*Quantitative*	How does it affect the revenue?
Portfolio – care volume	*Quantitative*	What are the changes in surgical volumes?
Portfolio – care type	*Qualitative*	What are the changes in type of surgery?
Sustainability	*Qualitative*	What are the implications on the strategic position of a hospital?

Table 14: The parameter metrics, assessment and scope from patient perspective

Effects on medical profession

Metric	*Assessment*	*Scope*
Composition	*Qualitative*	What does it implicate for the hospital staff directly involved with the surgeries?
Academic research	*Qualitative*	Does it affect the amount of academic research?
(Re)training and education	*Qualitative*	Does staff need to be (re)trained?

Table 15: The parameter metrics, assessment and scope from patient perspective

5.3 Scoring the evaluation framework

For readability, this research proposes a Likert scale to score how the outcomes of the model perform on all parameters. Per metric, the allocation outcomes are given a qualification from Table 16. During the semi-structured interviews, the experts were asked about the potential positive and negative effects of each parameter in different allocation outcomes. The responses gathered from these interviews served as the basis for establishing the scoring criteria shown in Table 17, Table 18 and Table 19.

Qualification	*Meaning*
- -	Negative effect
-	Slightly negative effect
0	Neutral effect
+	Slightly positive effect
+ +	Positive effect

Table 16: Scale for scoring the outcomes performances

Likert score	*Patient*				
	Travel time	Waiting time	Freedom of choice	Quality of surgery	Integral care pathway
- -	4+ types only in south or north	1 type has significant centralisation and/or all surgical care for these types is only at one hospital	40%+ care shifts	No types improvement expected	1+ additional hospitals share surgeries
-	3+ types only in south or north	2 type have significant centralisation and/or all surgical care for these types is only at one hospital	35 to 40% care shifts	>2 types improvement expected	1 additional hospital shares surgeries
0	2+ types only in south or north	3 type has significant centralisation and/or all surgical care for these types is only at one hospital	30 to 35% care shifts	>5 types improvement expected	No additional hospital shares surgeries
+	1 type only in south or north	3+ type has significant centralisation and/or all surgical care for these types is only at one hospital	25 to 30% care shifts	All types improvement but more improvement potential	Additional 1 care path integration
++	No types only in south or north	6+ type has significant centralisation and/or all surgical care for	30- % care shifts	All types improvement max	Additional 1+ care path integration

		these types is only at one hospital			

Table 17: Likert scoring criteria for patient perspective

Likert score	*Hospital system*				
	Resource usage	Revenue implications	Portfolio - care volume	Portfolio – care type	Sustainability
- -	4+ hospitals need extra capacity	45+% MAD	25+% MAD	9+ hospitals stop performing certain type	Negative impact on 1+ hospital's strategic positions
-	3+ hospitals need extra capacity	40 to 45% MAD	20 to 25% MAD	7+ hospitals stop performing certain type	Negative impact on 1 hospital's strategic positions
0	2+ hospitals need extra capacity	35 to 40% MAD	15 to 20% MAD	5+ hospitals stop performing certain type	Neutral impact on hospital strategic positions
+	1 hospital need extra capacity	30 to 35% MAD	10 to 15% MAD	3+ hospitals stop performing certain type	Positive impact on 1 hospital's strategic positions
++	No hospital need extra capacity	30- % MAD	10- % MAD	1 hospital stop performing certain type	Positive impact on 1+ hospital's strategic positions

Table 18: Likert scoring criteria for hospital sytem perspective

Likert score	*Medical profession*		
	Composition	Academic research	(Re)training and education
- -	Impact for 6+ specialist staff types	Only negative influence academic research	For 1+ tumour types re(training) or education needed
-	Impact for 5+ specialist staff types	Mostly negative influence academic research	For 1 tumour types re(training) or education needed
0	Impact for 3+ specialist staff types	Same amount negative as positive influence academic research	No significant re(training) or education needed
+	Impact for 1+ specialist staff types	Mostly positive influence academic research	Increase in efficiency for 1 tumour types re(training) or education
++	Impact for no specialist staff types	Only positive influence academic research	Increase in efficiency for 1+ tumour types re(training) or education

Table 19: Likert scoring criteria for medical profession perspective

Concluding, Section 5.1 showed that reports on centralisation in the Netherlands provide valuable insights into the relationship between centralisation and quality of care. They emphasize the importance of collaboration among stakeholders and the need for shared decision-making. The reports also discuss cascade effects, the impact on patients, healthcare professionals, organizations, and society, as well as financial implications. In 5.2 an evaluation framework is developed to assess the outcomes of the mathematical model and potential future scenarios within OncoZON. The framework aims to evaluate all scenarios consistently, based on predetermined criteria and using a transparent system. The framework considers not only the direct results of changes but also potential cascade effects. Nine prominent reports on centralisation in the Dutch healthcare system were used to construct the framework. Parameters are categorized into three perspectives: patient, hospital system, and the medical profession, providing a structured approach to evaluate the implications of changing surgery volumes. As explained in 5.3, The evaluation framework is scored using a Likert scale, which is based on insights gathered from semi-structured interviews with experts. These interviews explored the potential positive and negative effects of different allocation outcomes on each parameter.

Chapter 6: Results

In the results, the surgery allocation model is applied to the OncoZON region. First, the general model outcomes are discussed in Section 6.1. It is showed how an increase of robustness changes the care shifts and how the outcomes affect the capacity usage of the hospitals. Then, there are several scenarios selected in 6.2 for further analysis by means of the evaluation framework. At last, in 6.3 there is a sensitivity analysis done to see how changes in demand impact the outcomes.

6.1 The model outcomes for all scenarios

The final model from Chapter 4: Mathematical allocation model was programmed using R and the package OMPR (*Optimisation Modeling Package*) (Schumacher, 2022). It was solved with *Gurobi Optimizer version 10.0.1 build v10.0.1rc0*. The specifics regarding run time and nodes explored can be found in Appendix F: Model run specifics for different experiments.

The results can be divided into several outcomes of interest. At first, the general outcomes of the experiments are discussed. Table 20 comprises the objective, care shifts and total extra capacity. It is important to assess the objective values together with the care shift as this is a direct result of the allocation outcome. As the care shifts represent the number of surgeries that are redistributed to a different hospital compared to the current situation, it gives a good impression of the scale of displacement.

Exp name	*Experiment*	*Robustness (= # scenarios)*	*Objective value*	*# Care Shifts*	*Total extra capacity (ICU,OR,WARD)*		
Max	Norms all max	1	1619.9	**1311**	87.7	245.3	608.0
Min	Norms all min	1	636.6	525	29.8	118.2	195.8
1out6_1	1 out 6 to max	1	966.0	703	57.9	228.7	688.3
1out6_2	1 out 6 to max	2	1112.0	859	82.3	149.2	469.6
1out6_3	1 out 6 to max	3	1259.4	**983**	94.3	149.2	469.6
1out6_4	1 out 6 to max	4	1450.0	**1187**	82.3	149.2	541.3
1out6_5	1 out 6 to max	5	1589.0	**1309**	87.7	185.1	517.7
1out6_6	1 out 6 to max	6	1619.9	**1311**	87.7	245.3	608.0
2out6_1	2 out 6 to max	1	1156.7	863	90.0	248.8	466.6
2out6_2	2 out 6 to max	2	1259.4	**983**	94.3	149.2	469.6
2out6_3	2 out 6 to max	3	1259.4	**983**	94.3	149.2	469.6
2out6_4	2 out 6 to max	4	1450.0	**1187**	82.3	149.2	541.3
2out6_5	2 out 6 to max	5	1450.0	**1187**	82.3	149.2	541.3
2out6_6	2 out 6 to max	6	1589.0	**1309**	87.7	185.1	517.7
2out6_7	2 out 6 to max	7	1589.0	**1309**	87.7	185.1	517.7
2out6_8+	2 out 6 to max	8 to 15	1619.9	**1311**	87.7	245.3	608.0
3out6_1	3 out 6 to max	1	1280.1	994	65.1	281.4	668.8
3out6_2	3 out 6 to max	2	1589.0	**1309**	87.7	185.1	517.7
3out6_3	3 out 6 to max	3	1589.0	**1309**	87.7	185.1	517.7
3out6_4	3 out 6 to max	4	1589.0	**1309**	87.7	185.1	517.7
3out6_5	3 out 6 to max	5	1589.0	**1309**	87.7	185.1	517.7
3out6_6	3 out 6 to max	6	1589.0	**1309**	87.7	185.1	517.7
3out6_7	3 out 6 to max	7	1589.0	**1309**	87.7	185.1	517.7
3out6_8	3 out 6 to max	8	1589.0	**1309**	87.7	185.1	517.7
3out6_9+	3 out 6 to max	9 to 20	1619.9	**1311**	87.7	245.3	608.0

Table 20: Overview of general model outcomes

As expected, the experiment where all norms have their maximum value, known as the 'max' experiment, resulted in the highest number of care shifts at 1311, while the 'min' experiment, where all norms have their minimum value, resulted in the lowest number of care shifts at 525.

Across all experiments, a ‘maximum level of robustness’ was reached where the solutions remained the same and did not improve further. The ‘maximum level of robustness’ means that all possible norm combinations are taken into account, making the allocation sound against all possible scenarios. For the 1 out of 6 experiment, this maximum robustness was achieved when all six norm sets were included in the solutions. In the 2 out of 6 experiments, the upper limit was reached after a robustness level of 8, while in the 3 out of 6 experiments, this limit was reached after a robustness level of 9.

The results indicate that there is a limited number of unique solutions. For example, the experiment '1out6_3' produced the same outcome as both '2out6_3' and '2out6_4'. All cross-experiment identical solutions are marked in **bold**. Overall, there are only 9 unique allocation outcomes across all experiments. Figure 9 illustrates how the objective value and number of care shifts change as the robustness increases. The horizontal line segments at the same level represent identical outcomes. To visually represent the new allocation of surgery, Figure 10 shows the volumes with geographical allocation in the current situation (left) and the outcome of the experiment where all max norms are enforced (right). The allocation tables for all unique solutions can be found in *Appendix G: Overview of Distribution of Surgical Volumes*.

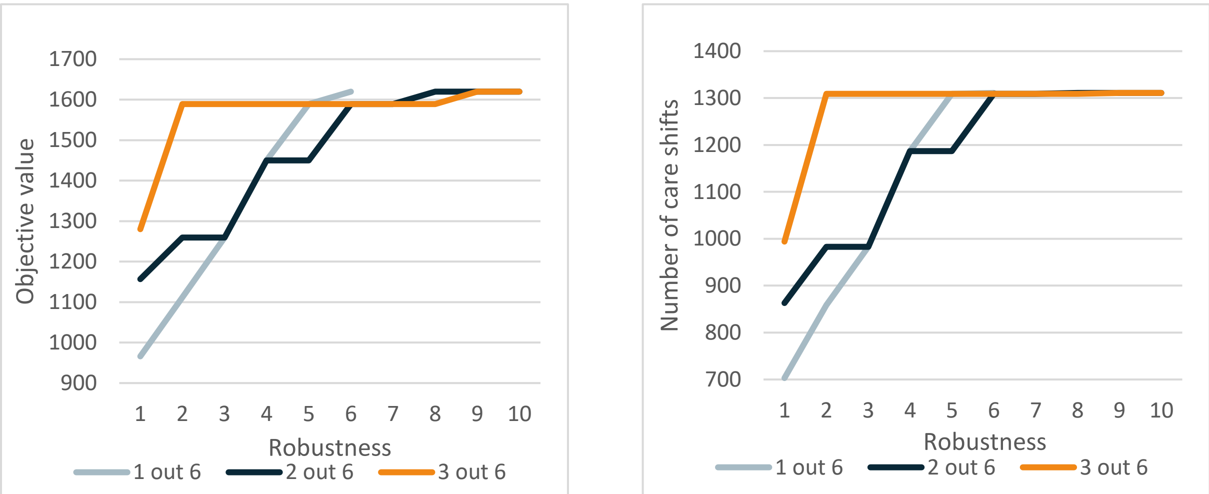

Figure 9: Impact of robustness on the objective value (left) and number of care shifts (right)

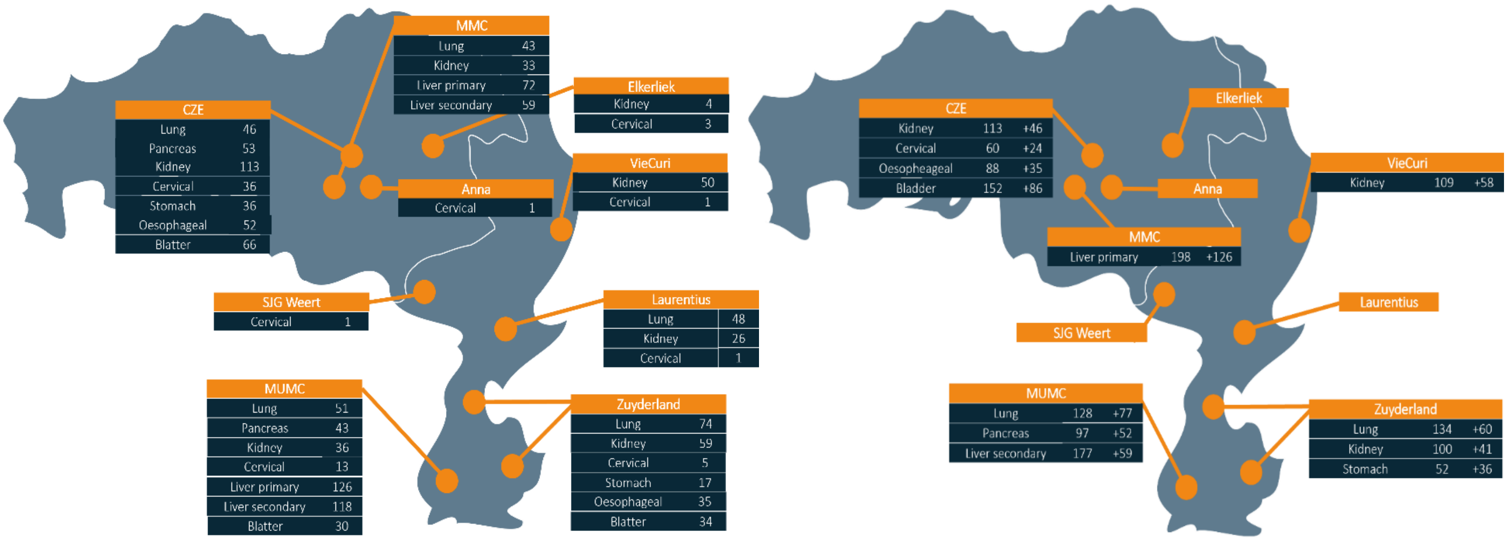

Figure 10: Allocation of surgery volumes in current situation (left) and max norm experiment

Implication on capacity

Next to the objective value, the allocation and the care shifts, it is important to see how the outcomes perform in terms of the usage of extra capacity. The extra capacity results are divided in extra ICU, OR and Ward, and all experiments are displayed separately. In all the figures, only the hospitals with additional capacity are included. This is because when capacity increases, hospitals must make portfolio choices, such as reducing other types of care or finding ways to expand their overall capacity. These results hold particular relevance and significance within the context of this study. Furthermore, the interviews conducted revealed that reallocating the "freed-up" capacity from hospitals that require less capacity after the new allocation is easier due to the high demand for care across all types, which makes it possible filling the space with other types of care.

Figure 12, Figure 11, and Figure 13 show the extra ICU capacity usage with the increasing robustness. It shows that CZE has predominantly constant additional use of ICU capacity, mostly due to allocation of high volumes of kidney, oesophageal and bladder surgery. Only in the first robustness = 1, in 3 out 6 experiments the extra ICU usage is lower, this is because there is a lower volume allocation of Bladder surgery. For MMC there are fluctuations in '1 out 6' as a result of the allocation of tumour type liver primary, 0 for robustness = 3 and 198 when robustness = 4. This has the opposite effect on the extra ICU usage of MUMC because the allocation for liver primary is 198 for robustness = 3 and 0 when robustness = 4.

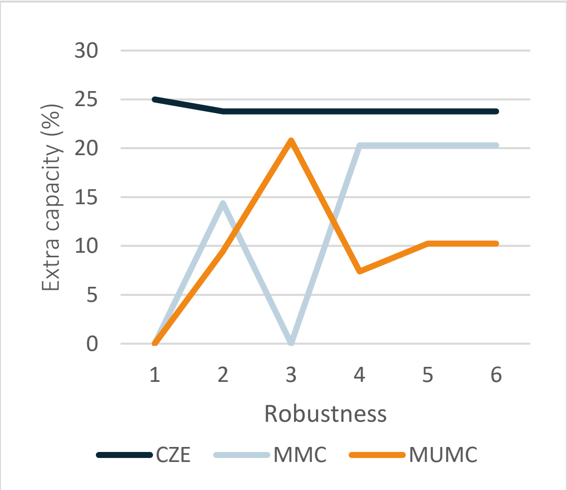

Figure 12: Extra ICU usage in the 1 out 6 experiments

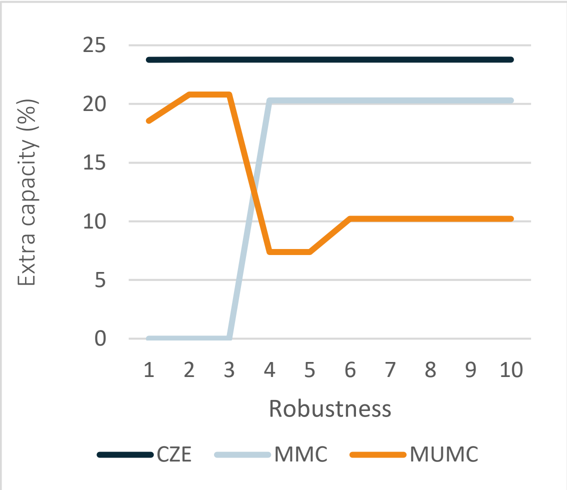

Figure 11: Extra ICU usage in the 2 out 6 experiments

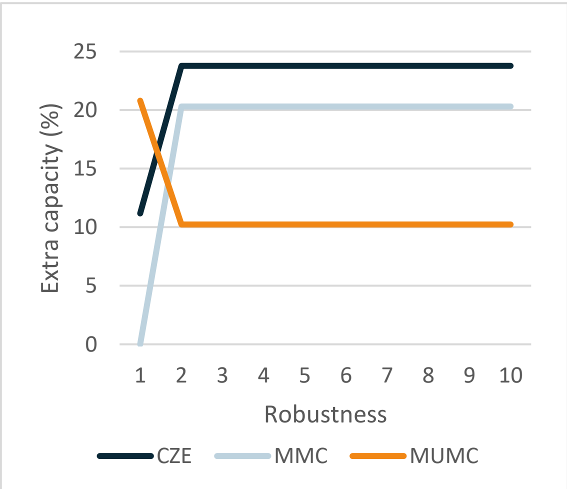

Figure 11: Extra ICU usage in the 1 out 6 experiments

The extra OR usage shown in Figure 15, Figure 14 and Figure 16 displays changes for VieCuri. In 1 out 6 the OR usage increases drastically at robustness = 5 and for the other two experiments at 6 and 2. This can be explained by the fact the norms that are enforced for tumour type kidney increase from 50 to 100 resulting in the increase of volumes at VieCuri. For Zuyderland, in the 1 out 6 and 3 out 6 experiments, the decrease in the middle of the Figure 15 and Figure 16 is a result of bladder surgery moving to CZE, and the increase afterwards is a results of the increase of kidney surgery (58 -> 100).

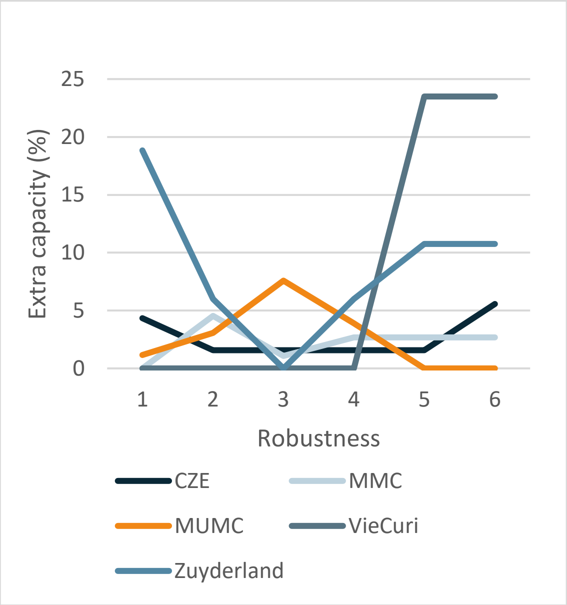

Figure 15: Extra OR usage in the 1 out 6 experiments

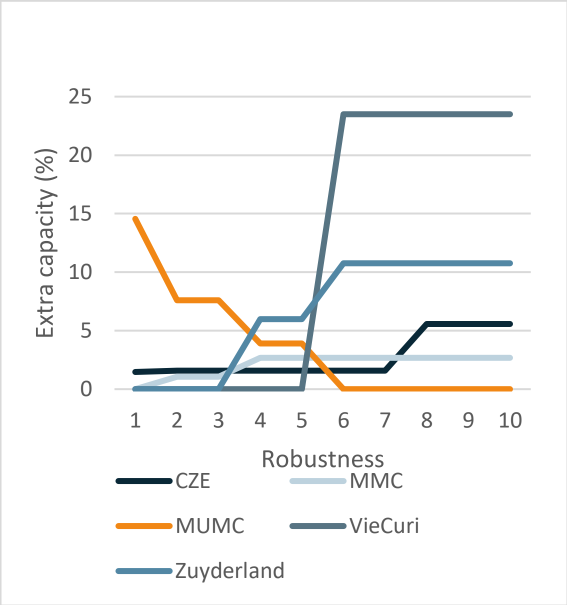

Figure 14: Extra OR usage in the 2 out 6 experiments

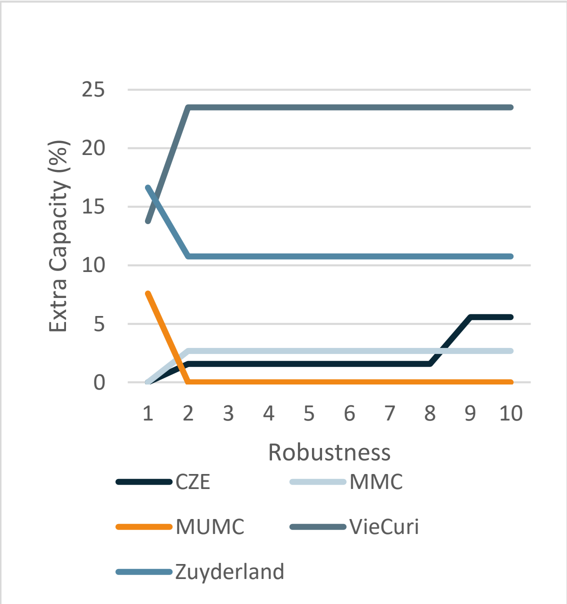

Figure 16: Extra OR usage in the 3 out 6 experiments

Figure 17, Figure 18 and Figure 19 overview the extra usage of Ward capacity, it shows that MMC experiences a peak in lower robustness levels followed by a decrease after a certain point. This is inflicted by the fact that lung surgeries are allocated at MMC in the lower robustness levels, but reaching higher robustness levels, the lung surgeries are allocated to MUMC which lowers the extra Ward usage of MMC. Zuyderland also starts with an increased ward usage in experiment 1 out 6 and 3 out 6, which decreases over the progress of robustness. This is a result of the initial allocation of tumour type bladder at Zuyderland, which is allocated at CZE after the norm of 100 is enforced.

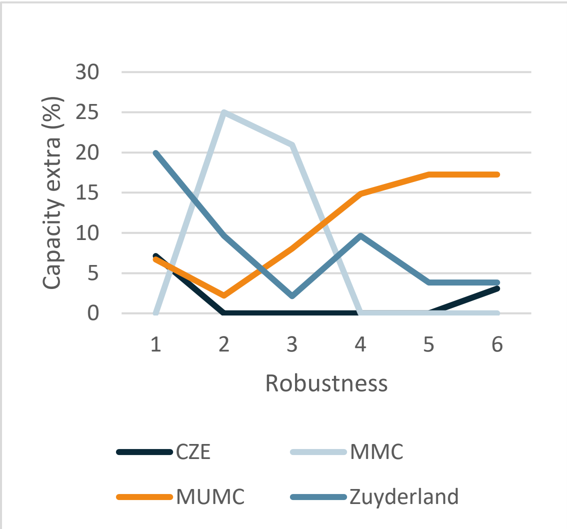

Figure 17: Extra Ward usage in the 1 out 6 experiments

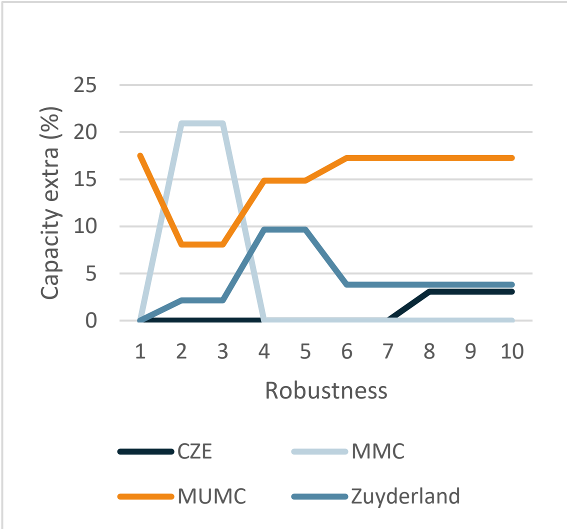

Figure 18: Extra Ward usage in the 2 out 6 experiments

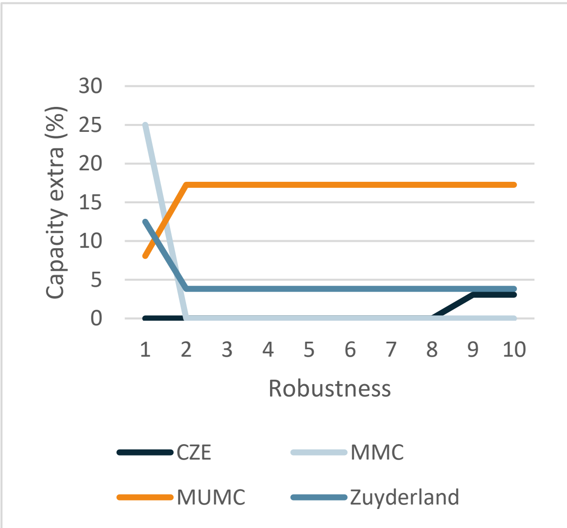

Figure 19: Extra Ward usage in the 3 out 6 experiments

Figure 11 to Figure 19 described above show that only for CZE, MMC, MUMC, VieCuri and Zuyderland there is extra capacity used, depending on number of norm scenarios that are included. The other four hospitals do not use additional capacity in any of the conducted experiments.

In Table 21, Table 22 and Table 23 below the average additional capacity is shown, this is expressed as a percentual increase compared to the current capacity. In general, it is not surprising that the 'larger' hospitals will need additional capacity. Because they have higher initial surgery volumes, they also have a higher total capacity (see *4.3 Model inputs*). This makes it more likely that the surgeries from smaller hospitals are referred to the larger ones for meeting the norms. CZE is the main user of extra ICU capacity, while VieCuri and Zuyderland do use extra ICU capacity. The increased IC usage of CZE can partly be explained by the fact that in most outcomes, all pancreas and oesophageal cancer surgeries are centralised there, and both have a high average ICU usage per operation. The highest percentage of extra OR capacity, which is seen at VieCuri, is the result of high kidney surgery volumes allocating at their location. For the extra Ward usage, MUMC needs the most additional capacity, which originates from high lung surgery volumes allocating at their location which has relatively high Ward usage.

Experiment	*CZE*	*MMC*	*MUMC*	*VieCuri*	*Zuyderland*
1 out 6	23.98	12.55	9.68	0.00	0.00
2 out 6	23.77	14.21	12.61	0.00	0.00
3 out 6	22.52	18.27	11.29	0.00	0.00

Table 21: The average % extra ICU usage over all levels of robustness

Experiment	*CZE*	*MMC*	*MUMC*	*VieCui*	*Zuyderland*
1 out 6	2.70	2.27	2.62	7.83	8.72
2 out 6	2.76	2.09	3.75	11.75	6.58
3 out 6	0.28	0.21	0.38	1.17	0.66

Table 22: The average % extra OR usage over all levels of robustness

Experiment	*CZE*	*MMC*	*MUMC*	*VieCui*	*Zuyderland*
1 out 6	1.70	7.66	11.05	0.00	8.17
2 out 6	0.92	4.19	14.96	0.00	4.27
3 out 6	0.61	2.50	16.34	0.00	4.69

Table 23: The average % extra Ward usage over all levels of robustness

6.2 Resulting effects on organisational parameters

Evaluation of the scenarios

To assess what the resulting effects would be in the various allocation outcomes, the framework constructed in chapter 4 is used to evaluate the outcomes. To keep the results concise and readable, there is made a selection of scenarios that are included for the evaluation. This selection is shown in Table 24, it shows the scenario specifics and the reasoning why the scenario is included, or not. The scenarios are named after the number of care shifts of the specific allocation. In Figure 20, Figure 21 and Figure 22 the selected scenarios are graphically displayed.

Number of Care shifts (= scenario name)	*Inclusion*	*Reasoning*
1311	Yes	Max robust version gives upper limit and evaluates 'worst-norm-case'
1309	Yes	Grouped with '1311' outcome, only difference is centralisation of cervical from Laurentius to CZE
1187	Yes	Outcome in both the 1 out 6 and 2 out 6 experiments
994	Yes	The solution of 3 out of 6 with robustness = 1 so this includes selection the 3 worst case scenarios
983	Yes	Outcome in both the 1 out 6 and 2 out 6 experiments
863	No	From interviews is it concluded that there is a high change that the norm for tumour type lung will be 100, so less interesting scenario
859	Yes	Low robustness, but lung ≥ 100 included
703	Yes	Low robustness, but lung ≥ 100 included
525	No	From interviews is it concluded that there is a high change that the norm for tumour type lung will be 100, so less interesting scenario

Table 24: All unique allocation outcomes of the model with the reason of inclusion or exclusion

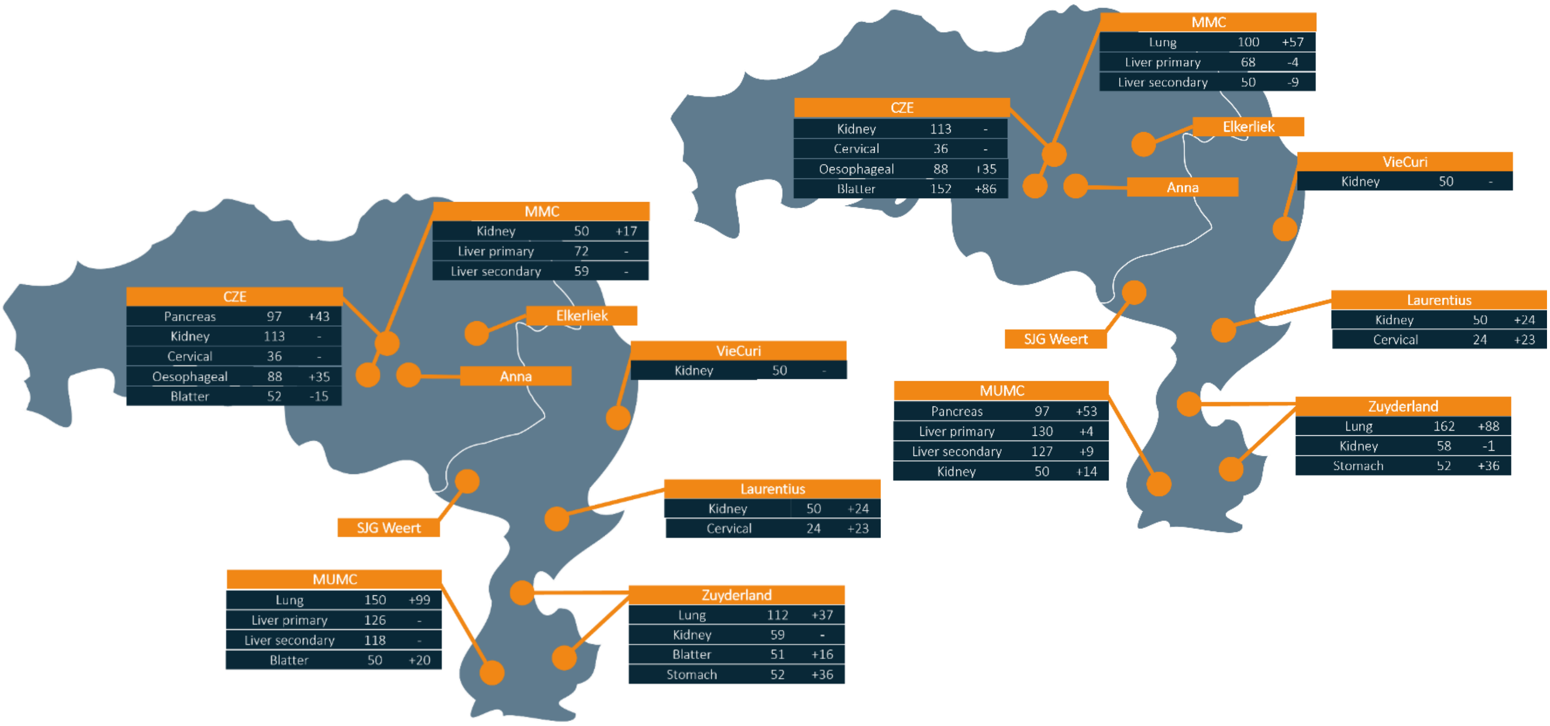

Figure 20: Allocation result of the scenario '703' (left) and '859' (right)

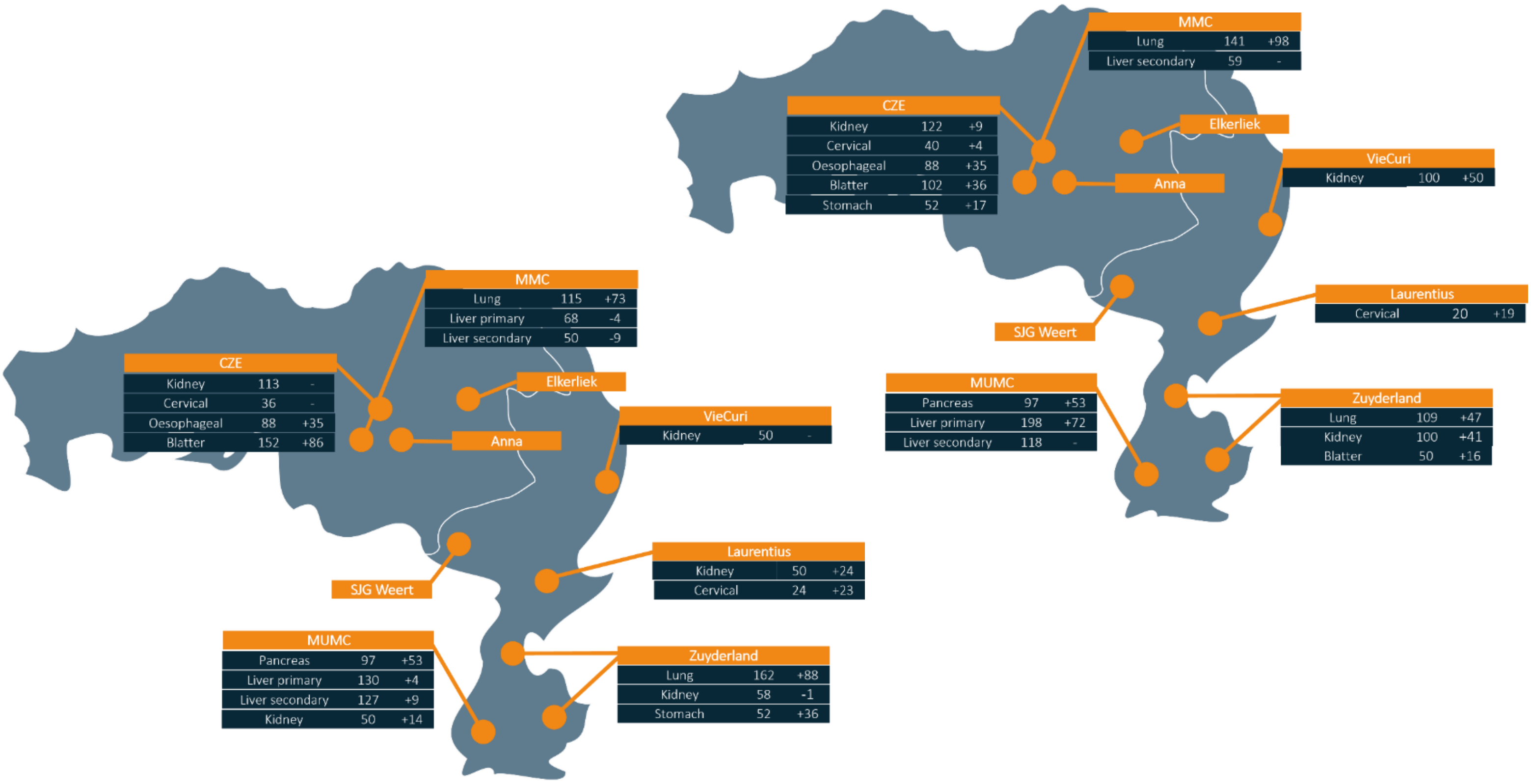

Figure 21: Allocation result of the scenario '983' (left) and '994' (right)

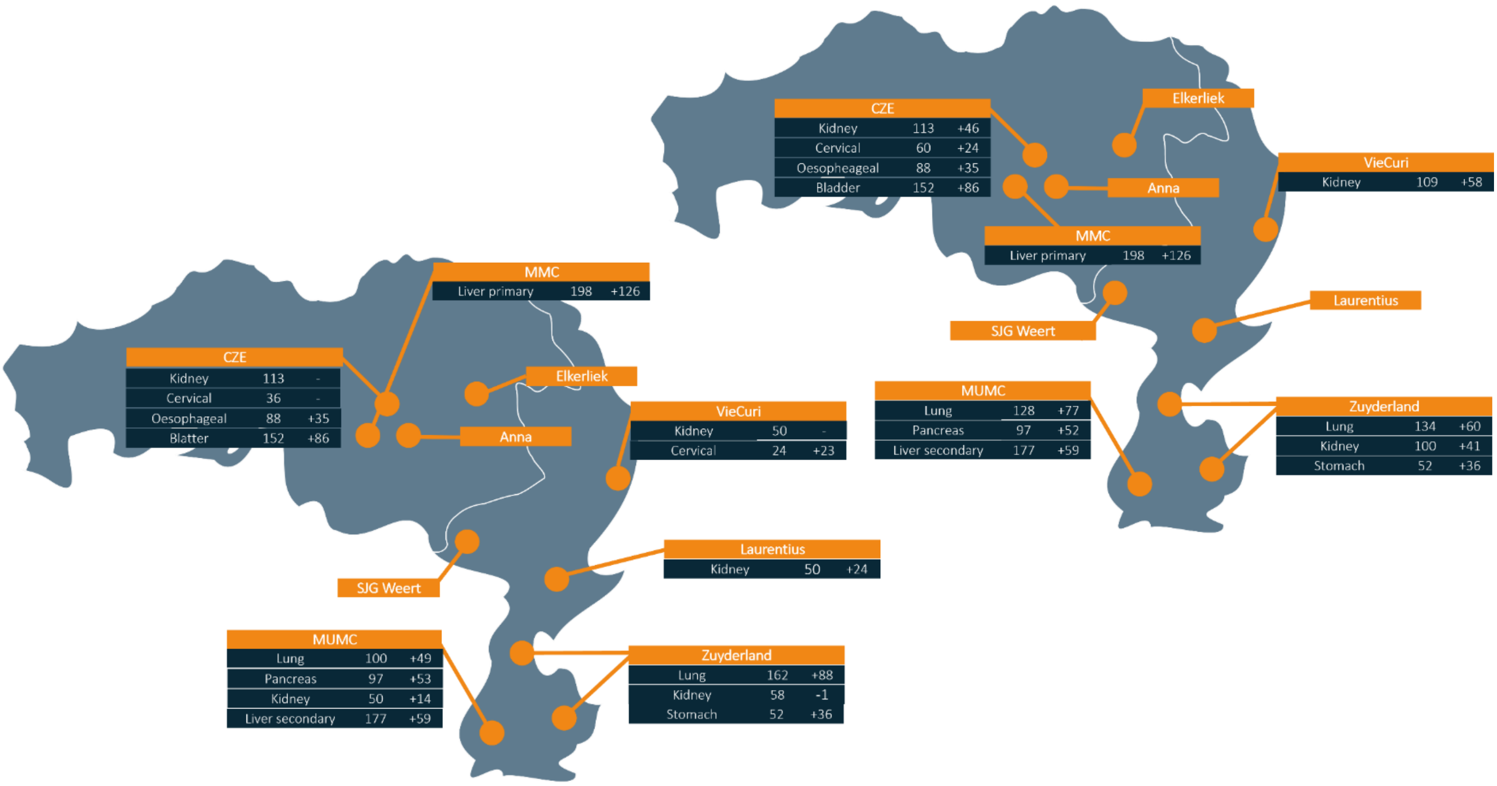

Figure 22: Allocation result of the scenario '1187' (left) and '1311' (right)

Table 25, Table 26 and Table 27 below present a summary of Likert scale scores for each parameter in the framework. In Chapter 5: Evaluation framework it was explained that the scoring criteria is based on the opinion of the interviewed specialist. For a more complete explanation of the evaluation, you can refer to the tables in *Appendix I: Detailed outcome evaluation framework*, which provides detailed information on each parameter with a description of how a specific scenario performs in relation to each parameter.

Scenario	*Patient*				
	Travel time	Waiting time	Freedom of choice	Quality of surgery	Integral care pathway
'703'	-	+	0	+	-
'859'	-	+	-	+	0
'983'	- -	+	-	+	0
'994'	-	+	-	+	0
'1187'	- -	+	- -	+	0
'1311'	- -	+	- -	+	0

Table 25: Performance of the selected scenario for the patient perspective

Table 25 shows the scores for all scenarios on parameters from the patient perspective. It shows negative scores for all scenarios in terms of travel time due to certain tumour types being centralised in either northern or southern hospitals. Increased centralisation of all tumour types leads to slightly reduced waiting times and slightly improved surgery quality due to higher hospital volumes and lower expected mortality rates. However, there is a decrease in freedom of choice as there are fewer hospitals to choose from. In scenario '703', there is also a decrease in freedom of choice, but the total percentage of care shifts is unique below 25%. The integral care pathway is mostly unaffected, but in '703' bladder surgery is shared between multiple hospitals, which is slightly negative from an organisational perspective.

Scenario	*Hospital system*				
	Resource usage	Revenue implications	Portfolio - care volume	Portfolio – care type	Sustainability
'703'	-	0	+	0	0
'859'	- -	++	0	0	0
'983'	- -	-	0	0	0
'994'	-	-	+	+	0
'1187'	- -	0	- -	-	0
'1311'	- -	- -	- -	-	-

Table 26: Performance of the selected scenario for hospital system perspective

Table 26 shows the scores for all scenarios on the parameters from the hospital system perspective. It shows slightly negative resource usage as all scenarios require additional capacity, some requiring extra robotic capacity. Revenue implications vary among scenarios with mean absolute deviation (MAD), indicating how percentual revenue changes deviate from the mean. '1311' has a high deviation at MAD: 45.6%, while '859' has a MAD of 24.9%. Changes in care volume are also expressed in MAD, with 1187 and 1311 having a MAD of 25+% due to high lung and bladder redistributions. The slightly negative and positive care type scores depend on whether oesophageal and stomach care is provided in one hospital (positive) or separated (negative). '1311' negatively affects Laurentius' sustainability by discontinuing all complex oncology care.

Scenario	Medical profession		
	Composition	Academic research	(Re)training and education
‘703’	**0**	**0**	**0**
‘859’	**-**	**-**	**0**
‘983’	**- -**	**-**	**0**
‘994’	**-**	**-**	**0**
‘1187’	**-**	**0**	**0**
‘1311’	**- -**	**0**	**0**

Table 27: Performance of the selected scenario for medical profession perspective

Table 27 shows the scores for all scenarios on parameters from the medical profession perspective. It shows (slightly) negative overall scores for composition due to separating oesophageal and stomach surgeries, which is not preferable because staff composition is suitable for providing both care together. Additionally, all scenarios, except '703', imply the discontinuation of certain specialists' work in several hospitals. Academic research is both positively and negatively affected by centralisation, with pancreas allocation at a single hospital being positive, and lung surgery discontinuation at northern hospitals being negative. (Re)training and education scores are neutral, as most staff involved in high complexity oncology care are experienced in treating various tumour types.

In Table 28, the most important characteristics of every scenario over all perspectives are shown.

Scenario	*Most important characteristics*
‘703’	For the **patient** it has a unique neutral performance for *freedom of choice* as the percentages of care shifts is below 30%. It also has a unique slightly negative performance for *integral care pathway* because bladder surgery initially located in CZE is now shared with other hospitals. For **medical profession**, there is a negative performance for academic research due to the allocation of lung, oesophageal, and stomach tumour types to fewer hospitals that are currently conducting *academic research* on these types.
‘859’	For **hospital system,** this scenario results in negative resource usage due to high capacity increases and the need for extra robotic resources. There are positive *revenue implications* due to lowest Mean Absolute Deviation (MAD) of below 30%.
‘983’	For **patient** it has a negative performance for *travel time* due to increases in travel time for > 5 tumour types. For **hospital system,** negative *resource usage* due to high capacity increases and the need for extra robotic resources. For **medical profession** a negative performance on *composition* is shown due to the separate oesophageal and stomach allocation.
‘994’	For **hospital system** negative *revenue implications* due to high MAD of 44.9%, originating partly from the fact that Laurentius has a revenue decrease of -€ 560.050,00 (-71,4%).
‘1187’	For **patient** it has a negative performance for *freedom of choice* as the percentages of care shifts is above 40% and a negative performance for *travel time* due to increase in travel time for > 5 tumour types. For **hospital system** negative *resource usage* due to high capacity increases and need for extra robotic resources and unique slightly positive *revenue implications* due to low MAD below 40%. For **medical profession**, there is a negative performance for academic research due to the allocation of lung, oesophageal, and stomach surgeries to fewer hospitals that are currently conducting *academic research* on these types.
‘1311’	For **patient** it has a negative performance for *freedom of choice* as the percentages of care shifts is above 40% and a negative performance for *travel time* due to increase in travel time for > 5 tumour types. For **hospital system** *negative revenue implications* due to highest MAD of 45.6% and negative *resource usage* due to high capacity increases and need for extra robotic resources. For **medical profession**, there is a negative performance for academic research due to the allocation of lung, oesophageal, and stomach tumour types to fewer hospitals that are currently conducting *academic research* on these types and a negative performance on *composition* due to the separate oesophageal and stomach allocation.

Table 28: Summarized overall performance of the selected scenarios

6.3 Sensitivity analysis

Sensitivity analysis is a critical tool used to evaluate the impact of changes in input parameters on model outcomes (Thabane et al., 2013). In this research, the total surgical demand estimates are subject to uncertainty, making sensitivity analysis necessary to assess the robustness of the findings. To keep the analysis concise, the experiment settings of the six selected scenarios were used to see how changes in the demand affects these outcomes.

For every scenario, changes in input parameters are evaluated by increasing and decreasing the demand for surgical procedures by 15, 25 and 35%, which are shown in Table 29. While the likelihoods of such changes are hard to determine exactly, it is necessary to test how they affect the outcomes. The total demand volumes are affected not only by the incidence trends but also by other factors such as the inclusion or exclusion of hospitals within the region and the specific criteria used to determine which types of surgeries are included in the total demand. These factors can significantly impact the overall care demand. Stress testing the outcomes is important to understand how significant changes in demand, such as these 'other factors', affect the outcomes. The aim is to strike a balance between being thorough and being practical, therefore three different levels of change are evaluated.

Furthermore, in Chapter 4: Mathematical allocation model, estimations were made for the total demand. However, it is worth noting that the estimations for tumour types cervical, primary liver, and secondary liver were not very precise. Therefore, it is important to examine how changes in demand specifically impact the allocation for these tumour types.

Type	*Current demand*	*Demand - 35%*	*Demand - 25%*	*Demand - 15%*	*Demand + 15%*	*Demand + 25%*	*Demand + 35%*
Lung	262	170	197	223	301	328	354
Pancreas	97	63	73	82	112	121	131
Kidney	322	209	242	274	370	403	435
Cervical*	60	39	45	51	69	75	81
Stomach*	52	34	39	44	60	65	70
Oesophageal	88	57	66	75	101	110	119
Liver primary	198	129	149	168	228	248	267
Liver secondary	177	115	133	150	204	221	239
Bladder*	152	99	114	129	175	190	205
Total	1408	915	1058	1196	1620	1761	1901

Table 29: Current volume with 15, 25 and 35% demand increase and decrease

* Due to decreased demand, the model faced infeasible solutions as the demand couldn't meet the minimum volume norms. To resolve this, constraints for those specific types were adjusted, centralizing them to their maximum capacity.

Table 30 below shows the objective values and care shifts when the model is ran with the +- 15, 25 and 35% demand values. Also, the ratio between the number of care shifts and the total demand is given. This shows what changes in care shifts can possibly be explained by the increase or decrease in demand, instead it being a result of changes in the number of shifts between hospitals.

Scenario (= # of shifts)	Total care demand changes (%)	Objective value	Care shifts	Ratio care shifts and total demand
703	- 35	805,4	806	0,44
	- 25	801,6	789	0,37
	- 15	700,8	671	0,28
	0	966	703	0,25
	+ 15	1367,9	677	0,21
	+ 25	2815,9	932	0,26
	+ 35	2195,2	784	0,21
859	- 35	805,4	806	0,44
	- 25	867,6	846	0,40
	- 15	817,2	740	0,31
	0	1112	859	0,31
	+ 15	1411,9	701	0,22
	+ 25	1760,6	767	0,22
	+ 35	2356,6	943	0,25
983	- 35	810,8	812	0,44
	- 25	912,7	891	0,42
	- 15	901,9	834	0,35
	0	1259,4	983	0,35
	+ 15	1411,9	701	0,22
	+ 25	1760,6	767	0,22
	+ 35	2365,9	955	0,25
994	- 35	905,7	894	0,49
	- 25	1022,3	967	0,46
	- 15	1083,8	1006	0,42
	0	1280,1	994	0,35
	+ 15	1407,4	769	0,24
	+ 25	1735	792	0,22
	+ 35	2316,2	921	0,24
1187	- 35	810,8	812	0,44
	- 25	947,8	926	0,44
	- 15	1026,7	904	0,38
	0	1450	1187	0,42
	+ 15	1450,5	731	0,23
	+ 25	1760,6	767	0,22
	+ 35	2365,9	954	0,25
1311	- 35	905,7	894	0,49
	- 25	1105,4	1065	0,50
	- 15	1193,5	1070	0,45
	0	1619,9	1311	0,47
	+ 15	1686,1	996	0,31
	+ 25	1932,7	932	0,26
	+ 35	2460,4	1054	0,28

Table 30: Objective values and care shifts for all scenarios

Changes in care shifts & allocation

The complete allocation outcomes can be found in *Appendix M: Allocation outcomes of the sensitivity analysi.* In general, the outcomes of the *ratio care shifts and total demand* in Table 30 above show that for a decrease in demand there is relatively higher number of care shifts needed. Overall, the lower volumes result in more care shifts to meet the required volume norms, resulting in a higher ratio. For the increase in demand the ratio is lower than the initial situation, it is logical that the number of care shifts decreases with higher demand because as the demand for surgeries increases, hospitals are more likely to meet their minimum volume norms without needing to centralize surgeries.

In certain scenarios of increased or decreased demand, there are specific tipping points in the volume norms for certain tumour types. These tipping points determine whether a particular hospital location can remain open or whether certain types of care can be maintained at a hospital. For example, if the total demand for kidney is 322 and the minimum volume norms per hospital is set at 100, three hospitals would be able to remain open. However, when demand is decreased by 15% or more, dropping below 300, it becomes impossible to keep three hospitals open. These tipping points play a crucial role in the allocation decision of the model. To give an overview of the changes per tumour type, Table 31 provides the most important changes in the allocation of the demand-changed situations compared to the initial solutions.

Type	*Most important changes in allocation*
Lung	In the initial solution, lung surgery is mostly centralised in two hospitals. In the -25% and -35% demand scenarios it becomes only possible to allocate at one hospital as the total demand gets below 200, while the norm is >100. The allocation is then in most cases at Zuyderland.
Pancreas	In the initial solution, pancreas surgery is centralised in one hospital. In all the increased demand scenarios it becomes possible to allocate at two hospital as the total demand gets above 100, while the norm is >50. This results that both CZE and MUMC keep providing pancreas surgeries.
Kidney	In the initial situation, kidney surgery has a total demand of 322. With increasing and decreasing of this demand this demand becomes below 300 or above 400. This enforces extra centralisation in case the norm is >100 and the total demand is below 300, and gives the possibility of opening four hospitals in the 'above 400' scenarios. This results, in most cases, that in the >100 norm scenario Laurentius remains providing kidney surgeries.
Cervical	In every norm >50 scenario, cervical surgeries need to be centralised in one hospital. A problem arises that for the decrease demand situation the total region's demand is not sufficient to meet the minimal volume norm. This implies the need to work together with hospitals outside the OncoZON region.
Stomach	In every scenario, stomach surgeries need to be centralised in one hospital. A problem arises that for the decrease situations -25 and 35% the total region's demand is not sufficient to meet the minimal volume norm. This implies the need to work together with hospitals outside the OncoZON region.
Oesophageal	In the initial solution, oesophageal surgery is centralised in one hospital. In all the increased demand scenarios it becomes possible to allocate at two hospital as the total demand gets above 100 and the norm is >50. This results that both CZE and Zuyderland keep providing oesophageal surgeries.
Liver primary	In the initial solution, liver primary surgery is centralised in one or two hospitals, depending on the enforced norm. In all the increased demand scenarios it becomes possible to allocate at two hospital, regardless of the 50 or 100 norm, as the total demand gets above 200. This means both MMC and MUMC keep providing liver primary surgery.
Liver secondary	In the initial solution, liver secondary surgery is centralised in one or two hospitals, depending on the enforced norm. In all the increased demand scenarios it becomes possible to allocate at two hospital, regardless of the 50 or 100 norm, as the total demand gets above 200. This means both MMC and MUMC keep providing liver primary surgery.
Bladder	In the initial solution, liver secondary surgery is centralised in one to three hospitals, depending on the enforced norm. A problem arises that for the decrease situation -35% the total region's demand is not sufficient to meet the minimal volume norm of >100. This implies the need to work together with hospitals outside the OncoZON region. For demand +35% situation, it becomes possible to allocate at two hospitals, regardless of the 50 or 100 norm, as the total demand gets above 200. This means both CZE and MUMC both remain providing bladder surgery.

Table 31: Changes in surgery allocation per tumour type for different demand scenarios

Changes for the evaluation framework

Changes in the allocation result lead to changes in the evaluation of the different parameters from the framework. Parameters such as *revenue implications, capacity usage, care volumes, and freedom of choice* may be influenced by changes in surgical volumes, regardless of whether the same hospitals perform the same procedures. It is essential to investigate whether demand changes affect allocation decisions, as this can guide the identification of robust scenarios that can handle fluctuations in demand.

Overall, the most important conclusions that can be drawn from the sensitivity analysis are:

(1) A decrease in demand can result in insufficient volumes in the region in meeting the new norms for the tumour types stomach and cervical and bladder, which means that the centralisation of these surgeries should then be arranged outside of OncoZON.

(2) A lot of allocation changes revolve around certain 'tipping points' where the increase of decrease in demand makes it (im)possible to open additional of fewer hospitals. These points represent boundaries that, when crossed, indicate a shift in feasibility. For example, if the minimum volume norm for kidney surgeries is 100 and the total demand is 322, three hospitals can operate. However, if demand drops by 15% or more, falling below 300, it becomes impossible to sustain three hospitals. Tipping points play a crucial role in allocation decisions, as the model's goal is to minimize the number of care shifts, keeping the allocation as much the same as the initial solutions is in most cases in line with the objective.

(3) When demand increases, it is important to consider the minimum volume norms. While increasing the number of hospitals allowed to perform surgeries may seem like a good option to increase for instance the *freedom of choice*, it carries a higher risk. This is because if the actual demand ends up being lower than estimated, hospitals may not meet the minimum volume norms enforced and/or need to work together outside of the current region.

Concluding, Section 5.1 showed the experiments conducted in the study revealed that the 'max' experiment, where all norms have their maximum value, resulted in the highest number of care shifts (1311), while the 'min' experiment, with all norms at their minimum value, had the lowest number of care shifts (525). A maximum level of robustness was achieved when all possible norm combinations were considered, leading to consistent solutions. The findings indicate a limited number of unique allocation outcomes, with only 9 unique allocations across all experiments. the implications of the allocation extra usage of ICU, operating room (OR), and ward capacity. CZE consistently requires extra ICU capacity due to the centralization of high-volume surgeries like kidney, oesophageal, and bladder surgeries. VieCuri sees the highest percentage increase in OR usage, mainly attributed to the allocation of high-volume kidney surgeries. MUMC necessitates the most additional ward capacity due to the allocation of lung surgeries. Overall, larger hospitals tend to require more additional capacity, as they receive referrals from smaller hospitals to meet the norms. In 5.2, the six most interesting scenarios are selected for further evaluation via de evaluation framework. The scenario names result from the number of care shifts corresponding to that scenario. From the patient perspective: All scenarios result in negative travel time scores due to centralization, but waiting times and surgery quality slightly improve. However, there is a decrease in freedom of choice as fewer hospitals are available, and in scenario '703', bladder surgery is shared among multiple hospitals. Regarding the hospital system perspective: Resource usage is slightly negative across all scenarios, with additional capacity and robotic resources required. Revenue implications vary, and some scenarios have high deviations. Changes in care volume and type impact the system, particularly with lung and bladder redistributions. From the medical profession perspective: Composition scores are slightly negative due to the separation of oesophageal and stomach surgeries. Discontinuation of specialists' work is implied in most scenarios, except '703'. Academic research is affected both positively and negatively, depending on the allocation, and (re)training and education scores are neutral. In 5.3 the sensitivity analysis involved increasing and decreasing the total demand for surgeries by 15%, 25%, and 35% for the earlier selected six scenarios. The results showed that a decrease in demand led to a higher number of care shifts, while an increase in demand resulted in a lower ratio of care shifts to total demand. Specific changes in allocation were observed for different tumour types, and tipping points were identified where changes in demand affected the feasibility of keeping hospitals open. The analysis highlighted that for certain types (bladder, cervical and stomach) the minimum volume norms were infeasible in decreasing demand situations due to the low total volumes in the region. This calls for the need for collaboration outside the region in certain scenarios.

Chapter 7: Discussion

In the discussion, the study's scientific (7.1) and practical contributions (7.2) are stated along with its limitations (7.3). Specifically, it is examined how the findings contribute to the field of robust modelling in health (resource) allocation problems, and what practical implications they have for the OncoZON region.

7.1 Scientific contribution

In this research, a mixed-integer linear program was formulated and used for allocating surgeries across different hospitals. The goal was to see how the uncertainty in the norms would change the outcome, and if using robust optimisation was applicable for this type of problem. Next to the traditional robust approach, a *scenario-robustness approach* was used to overcome over-conservativeness.

The model was inspired by the idea of a *cardinality-constrained approach* where the number of parameters that have their worst-case value is limited. Studies by Addis et al. (2014) and Aslani et al. (2019) showed that defining a budget of uncertainty addresses over-conservativeness well. In their studies, they showed a 100% feasibility guarantee of a robust tactical capacity plan while not being fully conservative. This research showed that is it also an option to first solve the allocation model for all norm combinations, to see which combinations result in the worst outcomes in terms of objective value. Then, the model was solved again with an increasing amount of combinations enforced, starting with the combinations that resulted in the worst outcomes. This approach is applicable in problems where it is already known that there is a limited subset of possible scenarios, and the aim is to be robust against the scenarios that would results in the worst outcomes, making the solution better performing in those cases. By gradually increasing the number of scenarios considered, the approach successfully reduced over-conservativeness. This allowed for a better understanding of how the allocation outcomes changed in not only the worst-case scenario.

Regarding the evaluation framework, this research provides a valuable example of how to incorporate expert opinion and literature review to create an evaluation base that can be used to assess different scenarios for surgical allocation. This approach could be a useful starting point for future academic studies that seek to address similar complex allocation problems, highlighting the importance of a mixed-methods approach in such research. In addition to its application in surgical allocation, the framework developed in this research can be adapted for use in other allocation problems such as resource allocation in manufacturing or transportation. It can also be used together with other evaluation methods like cost-benefit analysis to provide a better understanding of model outcomes. The framework is flexible and can be modified to incorporate different types of expert opinion or stakeholder input based on the research needs. Ultimately, it provides a versatile tool for evaluating complex allocation problems in various contexts.

7.2 Practical contribution

The study provides a practical contribution by delivering six relevant scenarios on how the different tumour-type surgeries could be distributed across the OncoZON region. For these scenarios, it gives insight into the direct quantitative consequences of each scenario in terms of increased care shifts and capacity use. This makes it easier to compare different scenarios and assess their potential impact. Decision-makers in hospitals are usually interested in scenarios that align with the (strategic) vision they have for the hospital, which includes deciding beforehand what tumour types they want to keep in the hospital. The model in this research could then also be used with additional constraints, to 'force' certain favourable scenarios.

The semi-structured interviews with the doctors provided useful hands-on information that was used to formulate the evaluation framework. Six different scenarios were evaluated via this framework to give a broader understanding of what is important when comparing different scenarios. This framework can easily be used to evaluate more scenarios and is also convenient for the implementation phase. In addition, the interviews provided CZE with new information on how the doctors view this centralisation challenge which is useful for speeding up the process of change. As described by Zuiderent-Jerak et al. (2012), and also apparent in the interview responses, quality is said to be the primary focus for centralisation. However, the decisions made during implementation are heavily influenced by organizational preferences, especially from the perspective of medical specialists.

While this allocation model is a useful tool in the current process, this study underlines it must be combined with expert opinion and a broader understanding of the complex factors that influence surgical allocation. To put it in sharper terms, it is questionable when addressing the general 'cancer care centralisation problem as an 'allocation problem', is the right choice. The sole aim should be to organise the oncology surgery landscape such that the increase of quality of care is the main goal. When approaching this problem as an allocation problem, it becomes more like some form of horse-trading. Doctors during the interviews pointed out that the discussion should be more about which tumour types to combine, and where to make 'central oncology centres' where all care is centralised instead of exchanging surgical volumes.

7.3 Limitations

The first limitation is the fact that this research is limited to only the surgeries of the included tumour types. Of course, surgeries are not stand-alone entities and come with pre- and post-operative care. The interviews showed that this is a very important aspect to take into account when deciding what is a preferred allocation of surgeries. If a certain type of care is offered at a hospital location, this asks for a complete organisation of the care pathway. While it may be feasible to organize pre- and post-operative care in different hospitals for some tumour types, this is not always possible. Some types of tumours require patients to stay in the same hospital throughout the entire treatment process, which means that performing the surgery at a single hospital, while providing pre- and post-operative care at another is not a viable option. Additionally, it is important to note that the separation of surgical and pre/post-operative care would not align with the centralisation goal in general.

Secondly, the current total capacity use for the included tumour types was estimated. This approach was necessary because data on total available capacity across all hospitals was not available. As a result, the model shows absolute and percentage changes in capacity use compared to current volumes for the included tumour types, but does not provide a perspective on total available capacity. It is important to note that creating additional capacity is not just a matter of doing less of one tumour type and more of another. Hospital capacity constraints vary between hospitals and some may have additional capacity available. In addition, reducing other types of care that use the same capacity could free up capacity that can be used to provide additional surgical cancer care.

The OncoZON region was chosen as the 'scope constraint' for the possible allocation of the surgeries. In reality, collaborations outside this oncology network are also possible. In fact, it is already the case for some tumour types that there are surgery referral structures that are superregional organised. The model proposed would be able allocate the surgeries nationally, when it is filled with additional data. For this research there was insufficient data regarding the hospital capacities known and the expert opinion was mainly focused on the OncoZON specifics which would have resulted in a skewed information collection.

Another limitation of this research includes that the estimated care demand for the OncoZON region was based on a rough estimation using national incidence trends. This may not accurately reflect the region's unique characteristics. As shown, for certain tumour types such as Cervical and Liver, the national incidence did not match the regional incidence well, leading to potentially inaccurate estimates. However, the sensitivity analysis showed that fluctuations in care demand are unlikely to significantly affect the allocation outcome in most cases, but could lead to problems with low-volume tumour types such as Cervical and Stomach. For those types, if the demand is lower than expected, hospitals are forced to organise these centralisations outside of OncoZON.

In this research, it was assumed that if a hospital stops performing certain surgeries, all cases would be transferred to another hospital. However, an alternative scenario could occur where doctors at the initial hospital propose different treatment options instead of referring patients elsewhere. This could affect the total demand for care in the region, as patients would still be treated at the initial hospital using alternative modalities.

At last, a possible limitation is that while the sensitivity analysis considers a 25% increase and decrease in demand for each tumour type, it assumes the same probability of fluctuation for all types. In reality, different types of cancer may have varying probabilities of experiencing such fluctuations in demand. Therefore, the sensitivity analysis may not fully capture the potential impact of demand fluctuations on the allocation outcome for each tumour type.

Chapter 8: Conclusions and recommendations

In the conclusions and recommendations, the five main conclusions that follow from the research questions and core problem are summarized in 8.1. It is shown how these conclusions contribute to the existing knowledge and highlight the practical implications. Furthermore, based on the findings of this research, recommendations are made in 8.2 together with possible future study areas which build on those recommendations.

8.1 Conclusion

The core problem addressed in this research was:

Catharina Hospital does not yet have sufficient insight into how the cancer care distribution within OncoZON will develop, based on the new cancer surgery volume norms and change in demand, and what the organisational effects of redistribution are.

To solve this problem, the following research question was answered:

How can the cancer care within OncoZON be distributed given the currently available surgical capacity, while being robust against the uncertain new cancer norms and increasing demand?

Following the core problem and the research questions under investigation, the most important conclusions are:

Scenario-robust optimisation is an applicable method for modelling uncertainty in health care settings.

The model used a two-step approach to solve the allocation problem. First, it solved the model for all norm combinations to identify the combinations that produced the worst outcomes. Second, for the *scenario-robust optimisation* the model was solved again with an increasing enforcement of the worst performing combinations, starting with the combinations that exhibited the worst outcomes. This approach for modelling the uncertainty in the minimum volume norms resulted in an extensive scenario analysis, and provided interesting insights in the changes in the allocation while the robustness of the model was varied. The scenario-robust approach sheds light on the impact of norm increases on the allocation and additional capacity usage. Instead of exhaustively exploring all possible combinations, this method prioritizes addressing the worst-case scenarios. This ensures that the best decisions are made, especially in situations where uncertain parameters impose strict constraints.

CZE, MUMC and Zuyderland are expected to be the leading high-volume hospitals considering all scenarios

In the majority of scenarios, CZE stands out as the leading hospital in terms of surgical volumes for various tumour types. It maintains the centralisation of both pancreas and oesophageal surgeries, showcasing its expertise in these areas. Moreover, they consistently handle high volumes for bladder and kidney surgery. MUMC takes the lead in providing liver surgery (both primary and secondary), and they also carry out lung surgeries in most cases. Zuyderland primarily focuses on stomach surgeries within its region. Additionally, they undertake lung surgery, which is also centralised from the northern hospitals (CZE and MMC) to them. In all scenarios considered Elkerliek, Anna, and SJG Weer hospitals no longer offer any form of high-complex oncology surgeries. They have made a shift away from providing these specialised surgeries, potentially reallocating their resources to other care.

The centralisation will have big consequences for the patient, hospital system and hospital profession.

For the six selected scenarios that were further analysed, the percentage shift of the new allocation compared to current allocation was on average 35.8%. This means that the proposed solutions state that more than 1/3 of the surgeries will take place at another hospital location after the centralisation. Applying the evaluation framework reveals that different effect parameters have a significant organizational impact. For the patient the allocations lead to negative travel times and decreased freedom of choice, but slightly reduced waiting times and improvement of surgery quality, with mostly minor negative impacts on the integral care pathway. For the hospital system, resource usage is slightly negative and revenue implications and changes in care volume vary among scenarios, with sustainability being affected by Oesophageal and Stomach care being provided in one hospital or separated. For the medical profession, separating oesophageal and stomach surgeries may slightly impact the overall scores for composition, while academic research is affected positively and negatively by centralisation, and (re)training and education scores remain neutral.

Additional redistribution of capacity is needed to facilitate the centralisation.

This research provides several scenarios on how the surgeries could be distributed across the different hospitals, however in every scenario's, this is resulting in extra capacity use compared to the current allocation. This result showed that it is not sufficient to only make a reallocation within the current used capacity. Larger hospitals, such as CZE, require additional capacity due to their higher surgery volumes. CZE shows increased ICU usage, ranging from 22.52% to 23.98%. VieCuri exhibits the highest percentage of extra operating room capacity, ranging from 1.17% to 11.75%. MUMC requires the most additional ward capacity, ranging from 11.05% to 16.34%. The results suggest that there is a need to consider other types of medical care, beyond cancer treatment, to both create capacity for additional surgical procedures and fill any extra capacity that may become available.

The challenge on the centralisation of cancer surgeries is not a mere allocation problem.

While the allocation model provides a good overview of the possible allocations, it also puts the focus on minimizing the number of care shifts, and minimizing the extra capacity. From the interviews with the doctors it can be concluded that this is possibly not the right approach. The primary focus should be on optimizing the quality of surgery. If centralising all cancer surgeries in one hospital is found to be the best way to achieve this goal, then efforts should be directed towards facilitating such an arrangement instead of trading tumour types across hospitals to keep all parties happy.

8.2 Recommendations & future research

Based on the obtained results, the discussion, and the conclusions drawn, the following recommendations can be made, along with possible research options for further research:

Make decisions as a (oncology) region and not as individual hospitals

It is recommended that decisions related to cancer care distribution be made at the regional level, rather than by individual hospitals. When the decision-making is more centralized the focus is more on how impact on all hospitals overall can be minimized, rather than prioritizing individual hospital interests. ***Possible future research:*** Research possible scenarios objectively within OncoZON including all hospital preferences to maximize the overall performance of the scenarios based on those preferences.

Extend the scope to national level

It is recommended to extend the scope of cancer care distribution decisions beyond the local (oncology) region to a national level. Firstly, this ensures that applicable volume norms can be set with respect to the total demand. This also makes it easier to assess how many hospital would be sufficient the provide surgeries for a certain type and decide how many are wanted in the whole country. Lastly, it also makes governmental decision-making easier as there are fewer different decisions to make per region but this can be done nationally. ***Possible future research:*** extend the current model with additional national hospital data and organise interviews from a diverse subset of hospitals. This could provide valuable insights into the optimal number of hospitals needed to provide high-quality cancer care at the national level.

Focus on quality evaluation

There has been research such as (de Haas et al., 2020b; Hsu et al., 2017) that provide evidence that higher surgical volumes decrease mortality rates. However, it is uncertain to what extent this increase in quality persists. To focus on the possible improvement in the Dutch health care system, is it important to research after the (first wave of) centralisation has taken place in the Netherland how this has affected the quality outcomes, and if there is ground to maybe further centralise certain tumour types. ***Possible future research:*** study the relationship of surgical volumes before and after the centralisation with respect to the quality outcomes.

Study how a scenario-robustness approach performs in problems with recourse

For this research the scenario-robustness approach was practical because it showed how the outcomes changes when taking into an increasing amount of possible norm scenarios. It also allowed to focus on the worst combination of norms first. However, it was hard to actually study how the model would perform when different norms scenarios than anticipated were to happen, as the problem did not have direct resulting cost or in loss quantified, which makes it hard to compare certain performances. ***Possible future research:*** A potential angle for future research could be to investigate the performance of the scenario-robustness approach in allocation problems that incorporate a recourse element. For instance, one could consider including costs associated with redistributing resources after an initial allocation decision is made. This could provide a more realistic and nuanced perspective on how the approach performs in practice.

References

2+ million invitations to get vaccinated against HPV in 2023 | RIVM. (2022). https://www.rivm.nl/en/news/more-than-two-million-invitations-to-get-vaccinated-against-hpv-in-2023

Aantal diagnoses kanker stijgt komend decennium tot 156.000 per jaar. (2022). https://iknl.nl/nieuws/2022/aantal-diagnoses-kanker-stijgt

Adams, W. C. (2015). Conducting Semi-Structured Interviews. *Handbook of Practical Program Evaluation: Fourth Edition*, 492–505. https://doi.org/10.1002/9781119171386.CH19

Addis, B., Carello, G., & Tànfani, E. (2014). A Robust Optimization Approach for the Operating Room Planning Problem with Uncertain Surgery Duration. *Springer Proceedings in Mathematics and Statistics*, *61*, 175–189. https://doi.org/10.1007/978-3-319-01848-5_14/COVER

Ahmadi, A. A., & Hall, G. (2012). *Robust Optimization Princeton University*.

Ardestani-Jaafari, A., & Delage, E. (2018). *Robust Optimization of Sums of Piecewise Linear Functions with Application to Inventory Problems on JSTOR*. https://www.jstor.org/stable/24740527

Aslani, N., Kuzgunkaya, · Onur, Vidyarthi, N., & Terekhov, D. (2019). *A robust optimization model for tactical capacity planning in an outpatient setting*. https://doi.org/10.1007/s10729-020-09528-y

Bai, M., Pasupathy, K. S., & Sir, M. Y. (2019). Pattern-based strategic surgical capacity allocation. *Journal of Biomedical Informatics*, *94*. https://doi.org/10.1016/J.JBI.2019.103170

Ben-Tal, A., El Ghaoui, L., & Nemirovski, A. (2009). *Robust Optimization*.

Ben-Tal, A., Goryashko, A., Guslitzer, E., & Nemirovski, A. (2004). Adjustable robust solutions of uncertain linear programs. *Mathematical Programming*, *99*(2), 351–376. https://doi.org/10.1007/S10107-003-0454-Y/METRICS

Ben-Tal, A., & Nemirovski, A. (1998). ROBUST CONVEX OPTIMIZATION. *MATHEMATICS OF OPERATIONS RESEARCH*, *23*(4).

Ben-Tal, A., & Nemirovski, A. (1999). Robust solutions of uncertain linear programs. *Operations Research Letters*, *25*(1), 1–13. https://doi.org/10.1016/S0167-6377(99)00016-4

Bertsimas, D., Brown, D. B., & Caramanis, C. (2007). *Theory and applications of Robust Optimization*.

Bertsimas, D., & Caramanis, C. (2010). Finite Adaptability in Multistage Linear Optimization. *IEEE Transactions on Automatic Control*, *55*(12), 2751–2766. https://doi.org/10.1109/TAC.2010.2049764

Bertsimas, D., & Goyal, V. (2013). On the approximability of adjustable robust convex optimization under uncertainty. *Mathematical Methods of Operations Research*, *77*(3), 323–343. https://doi.org/10.1007/S00186-012-0405-6

Bertsimas, D., & Sim, M. (2004). The price of robustness. *Operations Research*, *52*(1), 35–53. https://doi.org/10.1287/OPRE.1030.0065

Blanco, I., & Morales, J. M. (2017). An Efficient Robust Solution to the Two-Stage Stochastic Unit Commitment Problem. *IEEE Transactions on Power Systems*, *32*(6), 4477–4488. https://doi.org/10.1109/TPWRS.2017.2683263

Breuer, D. J., Kapadia, S., Lahrichi, N., & Benneyan, J. C. (2022). Joint robust optimization of bed capacity, nurse staffing, and care access under uncertainty. *Annals of Operations Research*, *312*(2), 673–689. https://doi.org/10.1007/S10479-022-04559-W

Burdett, R. L., Kozan, E., Sinnott, M., Cook, D., & Tian, Y. C. (2017). A mixed integer linear programing approach to perform hospital capacity assessments. *Expert Systems with Applications*, *77*, 170–188. https://doi.org/10.1016/J.ESWA.2017.01.050

Centraliseren van kankerzorg: goed plan | NTvG. (n.d.). Retrieved 13 December 2022, from https://www.ntvg.nl/artikelen/centraliseren-van-kankerzorg-goed-plan

Crossing the Quality Chasm: A New Health System for the 21st Century. (2001). https://doi.org/10.17226/10027

De concentratiehype voorbij | medischcontact. (n.d.). Retrieved 3 March 2023, from https://www.medischcontact.nl/nieuws/laatste-nieuws/artikel/de-concentratiehype-voorbij

de Haas, J., Heida, J. P., & Stoop, T. (2020a). *Concentratie van complexe ingrepen kan meer dan 200 sterftegevallen vermijden*. https://www.sirm.nl/nieuws/sirm-analyse-concentratie-van-complexe-zorg-kan-ruim-200-sterftegevallen-voorkomen

de Haas, J., Heida, J.-P., & Stoop, T. (2020b). *Concentratie van complexe ingrepen kan meer dan 200 sterftegevallen vermijden*. *SiRM.*

De Jonge, H. (2021). *Kamerbrief: Toekomstige organisatie van zorg voor patiënten met aangeboren hartafwijkingen*.

Denton, B. T., Miller, A. J., Balasubramanian, H. J., & Huschka, T. R. (2010). Optimal Allocation of Surgery Blocks to Operating Rooms Under Uncertainty. *Https://Doi.Org/10.1287/Opre.1090.0791*, *58*(4 PART 1), 802–816. https://doi.org/10.1287/OPRE.1090.0791

Een gezond vooruitzicht | Volksgezondheid Toekomst Verkenning. (2018). https://www.vtv2018.nl/

Filabadi, M. D., & Mahmoudzadeh, H. (2022). Effective Budget of Uncertainty for Classes of Robust Optimization. *Http://Pubsonline.Informs.Org/Journal/Ijoo*, *4*(3), 249–277. https://doi.org/10.1287/IJOO.2021.0069

Gökalp, E., Gülpınar, N., & Doan, X. V. (2020). Capacity Planning for Networks of Stem-Cell Donation Centers under Uncertainty. *Production and Operations Management*, *29*(2), 281–297. https://doi.org/10.1111/POMS.13090

Gourieroux, C., & Jasiak, J. (2010). Value at Risk. *Handbook of Financial Econometrics, Vol 1*, 553–615.

Guerriero, F., & Guido, R. (2011). Operational research in the management of the operating theatre: A survey. *Health Care Management Science*, *14*(1), 89–114. https://doi.org/10.1007/S10729-010-9143-6

Hans, E. W., Van Houdenhoven, M., & Hulshof, P. J. H. (2012). A Framework for Healthcare Planning and Control. *International Series in Operations Research and Management Science*, *168*, 303–320. https://doi.org/10.1007/978-1-4614-1734-7_12

Hermsen, M. (2022). *Nieuws Update, SONCOS/FMS*. https://www.onderzoekbijkanker.nl/trial-aanbieden.html

Honing, J., & Marres, H. A. M. (2012). *Concentratie van oncologische zorg: de medisch specialist moet aan zet* . http://www.rvz.net/publicaties/bekijk/

Hsu, R. C. J., Salika, T., Maw, J., Lyratzopoulos, G., Gnanapragasam, V. J., & Armitage, J. N. (2017). Influence of hospital volume on nephrectomy mortality and complications: a systematic review and meta-analysis stratified by surgical type. *BMJ Open*, *7*(9). https://doi.org/10.1136/BMJOPEN-2017-016833

Ikkersheim, D., Tanke, M., Van Schooten, G., De Bresser, N., & Fleuren, H. (2013). Modeling hospital infrastructure by optimizing quality, accessibility and efficiency via a mixed integer programming model. *BMC Health Services Research*, *13*(1), 1–9. https://doi.org/10.1186/1472-6963-13-220/FIGURES/2

IKNL. (2022). *Trendrapport Kanker in NL*.

Kanker, S., & Kankerbestrijding, K. (n.d.). *Kwaliteit van kankerzorg in Nederland*.

Kazemzadeh, N., Ryan, S. M., & Hamzeei, M. (2019). Robust optimization vs. stochastic programming incorporating risk measures for unit commitment with uncertain variable renewable generation. *Energy Systems*, *10*(3), 517–541. https://doi.org/10.1007/S12667-017-0265-5/METRICS

KPMG. (2018). *Cascade-effecten bij concentratie spoedzorg in beeld*.

Kwaliteitskader organisatie oncologische zorg. (2014).

K&Z, & VSOP. (2016). *Rapport, onderzoek naar: Concentratie van zorg en de effecten daarvan op de kwaliteit van de kindergeneeskunde in Nederland vanuit het perspectief van het kind en de ouders*. https://kindenzorg.nl/wp-content/uploads/2016/06/160622-Rapport-Concentratie-van-kindzorg-deel-1_perspectief-van-kindgezin.pdf

Levine, W. C., & Dunn, P. F. (2015). Optimizing Operating Room Scheduling. *Anesthesiology Clinics*, *33*(4), 697–711. https://doi.org/10.1016/J.ANCLIN.2015.07.006

LT, K., JM, C., & MS, D. (2000). *To Err is Human: Building a Safer Health System*. https://doi.org/10.17226/9728

Luo, M., & Cai, X. (2016). Surgical capacity sharing in an integrated hospital system. *2016 13th International Conference on Service Systems and Service Management, ICSSSM 2016*. https://doi.org/10.1109/ICSSSM.2016.7538638

Motallebi Nasrabadi, A., Najafi, M., & Zolfagharinia, H. (2020). Considering short-term and long-term uncertainties in location and capacity planning of public healthcare facilities. *European Journal of Operational Research*, *281*(1), 152–173. https://doi.org/10.1016/J.EJOR.2019.08.014

Multidisciplinaire normering oncologische zorg in Nederland Platform Oncologie-SONCOS. (n.d.).

Nederlandse Zorgautoriteit. (2022). *Rapportage impactanalyse concentratie interventies bij patiënten met een AHA*. https://puc.overheid.nl/nza/doc/PUC_728208_22/1/

NKR Cijfers | Incidentie - Grafiek. (2023). https://nkr-cijfers.iknl.nl/#/viewer/9b61e1e1-ef2a-49da-b085-0c8f7a90dce3

NZa. (2022). *Rapportage impactanalyse concentratie interventies bij patiënten met een aangeboren hartafwijking*.

Oncologisch Netwerk Zuidoost-Nederland - OncoZON. (2023). https://www.oncozon.nl/

Otten, T. M., Grimm, S. E., Ramaekers, B., & Joore, M. A. (2023). Comprehensive Review of Methods to Assess Uncertainty in Health Economic Evaluations. *PharmacoEconomics*, 1–14. https://doi.org/10.1007/S40273-023-01242-1/TABLES/3

Performation Portal. (2023). https://login.performation.com/core/Account/Login?ReturnUrl=%2Fcore%2Fconnect%2Fauthorize%2Fcallback%3Fclient_id%3Dportal%26redirect_uri%3Dhttps%253A%252F%252Fportal.performation.com%252F%26response_type%3Dcode%26scope%3Dopenid%2520profile%2520email%26state%3Dc5527d054dfe4f96bdf4ee4e8991a0e8%26code_challenge%3DBCUEgLF1kXPQgXC7oV7Mx-1XEtix56PFX64vuEFaNWE%26code_challenge_method%3DS256%26response_mode%3Dquery

ProfoundQa. (2022). *What is the difference between SO and RO?* https://profoundqa.com/what-is-the-difference-between-stochastic-and-robust-optimization/

Raad, S.-E. (2021). *Advies Aan de slag voor de zorg : een actieagenda voor de zorgarbeidsmarkt*. www.ser.nl

Roos, E., & Hertog, D. (2020). Reducing conservatism in robust optimization. *INFORMS Journal on Computing*, *32*(4), 1109. https://doi.org/10.1287/ijoc.2019.0913

Roshanaei, V., Luong, C., Aleman, D. M., & Urbach, D. R. (2017). Collaborative operating room planning and scheduling. *INFORMS Journal on Computing*, *29*(3), 558–580. https://doi.org/10.1287/IJOC.2017.0745

Samanlioglu, F. (2013). A multi-objective mathematical model for the industrial hazardous waste location-routing problem. *European Journal of Operational Research*, *226*(2), 332–340. https://doi.org/10.1016/J.EJOR.2012.11.019

Schumacher, D. (2022). *Model and Solve Mixed Integer Linear Programs [R package ompr version 1.0.3]*. https://CRAN.R-project.org/package=ompr

Simchen, E., Sprung, C. L., Galai, N., Zitser-Gurevich, Y., Bar-Lavi, Y., Gurman, G., Klein, M., Lev, A., Levi, L., Zveibil, F., Mandel, M., & Mnatzaganian, G. (2004). Survival of critically ill patients hospitalized in and out of intensive care units under paucity of intensive care unit beds. *Critical Care Medicine*, *32*(8), 1654–1661. https://doi.org/10.1097/01.CCM.0000133021.22188.35

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, *104*, 333–339. https://doi.org/10.1016/J.JBUSRES.2019.07.039

Taskforce Oncologie. (2022). *Oncologienetwerken in beeld*.

Thabane, L., Mbuagbaw, L., Zhang, S., Samaan, Z., Marcucci, M., Ye, C., Thabane, M., Giangregorio, L., Dennis, B., Kosa, D., Debono, V. B., Dillenburg, R., Fruci, V., Bawor, M., Lee, J., Wells, G., & Goldsmith, C. H. (2013). A tutorial on sensitivity analyses in clinical trials: The what, why, when and how. *BMC Medical Research Methodology*, *13*(1), 1–12. https://doi.org/10.1186/1471-2288-13-92/TABLES/2

van den Berg, L. M. M., Gordon, B. B. M., Kleefstra, S. M., Martijn, L., van Dillen, J., Verhoeven, C. J., & de Jonge, A. (2021). Centralisation of acute obstetric care in the Netherlands: a qualitative study to explore the experiences of stakeholders with adaptations in organisation of care. *BMC Health Services Research*, *21*(1), 1–9. https://doi.org/10.1186/S12913-021-07269-4/FIGURES/2

Van, O., & Zorg, O. (2020). *Een handreiking voor belangenbehartigers*.

van Volksgezondheid, M., & en Sport, W. (2022). *Integraal Zorg Akkoord - Samen werken aan gezonde zorg*.

Wijsman, B. P. (2013). Concentratie van zorg: een noodzaak in Nederland. *Tijdschrift Voor Urologie 2013 3:2*, *3*(2), 30–32. https://doi.org/10.1007/S13629-013-0008-X

Wisittipanich, W., Boonmee, C., Khwanngern, K., Chattinnawat, W., & Woschank, M. (2021). A MATHEMATICAL MODEL FOR MULTI-PERIOD SURGICAL SCHEDULING WITH CAPACITY CONSTRAINT. *Journal of Advanced Manufacturing Technology (JAMT)*, *15*(2), 1985–3157. https://jamt.utem.edu.my/jamt/article/view/6163

Zuiderent-Jerak, Kool, & Rademakers. (2012). *De relatie tussen volume en kwaliteit van zorg: tijd voor een brede benadering.*

Appendices

Appendix A: Volume requirements per tumour type

Type	*Statement in report (*Multidisciplinaire Normering Oncologische Zorg in Nederland Platform Oncologie-SONCOS, 2022)
Lung	In a healthcare facility, at least 20 lung resections must be performed per year, defined as segmentectomy, lobectomy, and pneumectomy. The resections are performed by a certified lung surgeon or thoracic surgeon.
Pancreas	At least 20 pancreaticoduodenectomies are performed per year, per location.
Kidney	Healthcare facilities that perform surgical treatment of renal cell carcinoma must perform at least 10 oncological renal procedures and diagnose/treat at least 20 new patients with renal cell carcinoma per year.
Cervical	At least 20 (radical) surgical procedures for cervical cancer must be performed per healthcare facility per year, calculated over a period of 3 years.
Stomach	At least 20 gastrostomies for gastric cancer must be performed per year, per location.
Oesophageal	At least 20 oesophagus resections for oesophageal cancer must be performed per year, per location.
Liver primary	At least 20 liver resections must be performed per year, per location. For patients with advanced liver fibrosis/cirrhosis, the policy is coordinated with a liver transplantation centre.
Liver secondary	At least 20 liver/bile duct resections must be performed per year, per location.
Bladder	The number of cystectomies for bladder carcinoma must be a minimum of 20 per year per site from 1 January 2019, performed by qualified urologists.

Table 32: Minimum Annual Surgical Volume Requirements per tumour type

Appendix B: Topic list & interview script

Interview Guide

Semi-structured interviews with doctors from CZE

Preparation

- Participants will receive information about the study and the informed consent form by email a week in advance. A reminder will be sent two days prior to the interview.
- Informed consent form completed and signed.

Interview introduction

- Welcome and introduction.
- The reason why respondents were selected.

Graduation research and purpose interview description

Under the guidance of Equalis & Vintura, graduating student Timon Metz will spend the next five months researching the effects of centralisation and distribution of oncological care within OncoZON. The course in question (Technical Business Administration in the direction of 'Healthcare Technology & Management') focuses on modelling healthcare issues in order to provide support for decision-making.

The aim of the study is to identify possible shifts in cancer operations, taking into account the uncertainty in standards and overall healthcare demand. To weigh up different outcomes, and how desirable and feasible they are, interviews are conducted to explore the (organisational) consequences of the shifts.

This research is commissioned by Catharina Hospital, but OncoZON is looking broadly at the possible shifts. The aim of this interview is therefore also to look more broadly at the important factors for the tumour types in question, and not only from a CZE perspective.

Start interview

Take stock of whether all participants have read/filled in the information sheet, informed consent.

Topic 1: General Trend

Questions:

1. In general, how do you view centralisation within cancer care?
2. Are you involved in organising these shifts, and if so in what way?

Topic 2: Medical Framework

Questions:

1. Are there any tumour types that should preferably be treated at the same hospital?
2. *[Discuss estimated the IC/OK/KL capacity estimates of the tumour type*] To what extent do you consider these capacity estimates correct?

3. To what extent is benchmarking these capacities an accurate way of estimating capacity at other hospitals?
4. Which capacity is 'multi-deployable' and which is specific per tumour type (specific doctors or nursing staff, or tumour-transcending deployable staff?)?
5. To what extent could a hospital create additional capacity for additional cancer care? And on what does this depend?
6. To what extent are all components of the care pathway performed at one location? Can you provide an estimate for the other hospitals?

Topic 3: Care demand & norms

Questions:

1. Are there any special circumstances to be identified around this demand development?
2. Which tumour types do you expect to be included in the first tranche? And which ones in the second?
3. What level of minimum volume norms do you expect for this specific type?

Topic 4: Organizational framework

Questions:

1. In which collaborations/networks do you expect the shifts (of this tumour type) to be arranged? Care office, oncology network, beyond?
2. What are the effects on training if a particular (tumour) type of care is dropped?
3. What are the effects on scientific research if a particular (tumour) type of care is dropped?
4. How do you expect staffing levels to change due to changes in numbers of certain (tumour) type of care?
5. How do you view the possibility of deploying doctors/nurses at multiple sites? And what do you think are the advantages and disadvantages of this?
6. In your opinion, what are other conceivable mitigating effects to make further centralisation have fewer negative effects?

Topic 5: Other questions

Questions:

1. What do you think has not yet been named but is relevant to include in the consideration?
2. Would you like to participate in a feedback of the scenarios and give your (brief) opinion on them?

Appendix C.1: Deterministic model

The start model for allocating the surgeries across the OncoZON region, with deterministic values for the norms. To solve for the various norm combinations, the $\boldsymbol{Norm_t}$ parameter is changed for every instance.

Sets

SurgTypes	The tumour types	With index **t**
Hospitals	The hospitals	With index **h**
Capacities	The type of capacities	With index **c**

Parameters

Demand (t)	Total demand for tumour type **t**
Norms (t)	The minimal volume norm for tumour type **t**
CapHosp (h,c)	The total capacity of hospital **h** of capacity **c**
Cap(t,c)	The amount of capacity **c** used for one surgery of type **t**
CurrSurg (t,h)	The current number of surgeries of type **t** at hospital **h**
BigM	A large, positive number
OpenNow(t,h)	1, if hospital **h** is performing surgeries of type **t** currently (CurrSurg[t,h] > 0) 0, otherwise
WeightCap(c)	The weight for extra capacity of type **c**

Decision variables

AllocatedSurg (t,h)	Number of surgeries of type **t** assigned to hospital **h**
OpenOrNot (t,h)	1, if hospital **h** is assigned to perform surgeries of type **t** 0, otherwise
CareShifts[t,h]	Extra variable for linearization of the absolute value of AllocatedSurg[t,h]-CurrSurg[t,h]
CapExtra[h,c]	The amount of extra capacity used at hospital **h** of capacity type **c**

The model

$$\textbf{minimize} \quad \sum_t \sum_h CareShifts_{t,h} + \sum_h \sum_c (CapExtra_{h,c} * WeightCap_c \quad [A]$$

Subject to

$$AllocatedSurg_{t,h} - CurrSurg_{t,h} \leq CareShifts_{t,h} \quad \forall(t,h) \quad [1]$$

$$-CareShifts_{t,h} \leq AllocatedSurg_{t,h} - CurrSurg_{t,h} \quad \forall(t,h) \quad [2]$$

$$\sum_h AllocatedSurg_{t,h} \geq Demand_t \quad \forall(t) \quad [3]$$

$$\sum_t (AllocatedSurg_{t,h} * Cap_{t,h,c}) \leq CapHosp_{h,c} + CapExtra_{h,c} \quad \forall(h,c) \quad [4]$$

$$AllocatedSurg_{t,h} \leq BigM * OpenOrNot_{t,h} \quad \forall(t,h) \quad [5]$$

$$AllocatedSurg_{t,h} \geq OpenOrNot_{t,h} \quad \forall(t,h) \quad [6]$$

$$AllocatedSurg_{t,h} + (1 - OpenOrNot_{t,h}) * BigM \geq Norm_t \; \forall(t,h) \quad [7]$$

$$OpenNow_{t,h} \geq OpenOrNot_{t,h} \; \forall(t,h) \; [9]$$

Where

$$AllocatedSurg_{t,h}, CareShifts_{t,h}, CapExtra_{h,c} \geq 0$$

$$OpenOrNot_{t,h}, \in \{0,1\}$$

Appendix C.2: full robust model

To make a full robust model the box of uncertainty approach is used. Two additional parameters are used:

$\overline{Norms_t}$ = Mean of the norm for type t

$DeviationN_t$ = max deviation from the mean norm for type t

ζ_n - box uncertainty norm, number between -1 and 1

[7] needs to take into account the uncertainty in the norms, and be robust against the worst-case realisation.

$$AllocatedSurg_{t,h} + (1 - OpenOrNot_{t,h}) * BigM \geq Norm_t \; \forall(t,h) \; [7]$$

Becomes

$$AllocatedSurg_{t,h} + (1 - OpenOrNot_{t,h}) * BigM \geq Norm_t \; \forall(t,h) + DeviationN_t * \zeta_n \; [7]$$

The aim is to assess the worst case scenario, so when the norms are the highest. This is the case when ζ_n has value 1. This means that for the full robust model the deterministic model is changed to:

$$AllocatedSurg_{t,h} + (1 - OpenOrNot_{t,h}) * BigM \geq Norm_t \; \forall(t,h) + DeviationN_t [7]$$

Which effectively means that for all tumour types the max norms are enforced.

Appendix D: Estimation of the total care demand

Table 33 and Table 34 show the origin of the numbers displayed in Table 6. These numbers are used to compare the incidence of the Netherland which those of the combined region Limburg + Brabant.

Tumour type	*Year*	*Incidence (absolute)* *(NKR Cijfers | Incidentie - Grafiek, 2023)*	*2016-2019 delta*
Esophageal cancer	2019	2535	1,157222666
Oesophageal cancer	2016	2506	
Gastric cancer (excl. cardiac cancer)	2019	1075	-9,052453469
Gastric cancer (excl. cardiac cancer)	2016	1182	
Liver cancer	2019	1079	26,4947245
Liver cancer	2016	853	
Pancreatic cancer	2019	2893	7,546468401
Pancreatic cancer	2016	2690	
Lung cancer	2019	14354	7,407961688
Lung cancer	2016	13364	
Cervical cancer	2019	906	12,40694789
Cervical cancer	2016	806	
Kidney cancer	2019	2776	0,579710145
Kidney cancer	2016	2760	
Bladder cancer	2019	6777	3,655552157
Bladder cancer	2016	1508	

Table 33: Incidence trends from 2016-2019 for the Netherlands

Tumour type	*Year*	*Incidence (absolute)* *(NKR Cijfers | Incidentie - Grafiek, 2023)*	*2016-2019 delta*
Esophageal cancer	2019	518	-1,893939394
Oesophageal cancer	2016	528	
Gastric cancer (excl. cardiac cancer)	2019	267	-6,968641115
Gastric cancer (excl. cardiac cancer)	2016	287	
Liver cancer	2019	274	18,10344828
Liver cancer	2016	232	
Pancreatic cancer	2019	642	7,718120805
Pancreatic cancer	2016	596	
Lung cancer	2019	3297	5,167464115
Lung cancer	2016	3135	
Cervical cancer	2019	211	-0,938967136
Cervical cancer	2016	213	
Kidney cancer	2019	621	-0,798722045
Kidney cancer	2016	626	
Bladder cancer	2019	1620	7,427055703
Bladder cancer	2016	1508	

Table 34: Incidence trends from 2016-2019 For Limburg + Brabant

Appendix E: Study basis for the evaluation framework

Title	*Research goal*	*Studied parameters/effects*
Cascading effects in emergency care centralisation in view (KPMG, 2018)	Identify possible cascade effects that may occur in a hospital that does not provide certain emergency care after centralisation	- Travel time / transport time patients - Change in Staff composition - Change in amount of work - Staff expertise - Quality of care - Change in use of equipment / rooms - Financial implications
The relationship between volume and quality of care-Time for a comprehensive approach (Zuiderent-Jerak et al., 2012)	Focus on a number of cases in the field of centralisation and volume increase to asses different stakeholder perspectives	- Volume-quality relation - Hospital strategic positioning - Staff composition - (re)training staff - Competition between hospitals - Freedom of choice patient - Accessibility – all care in one - Financial position hospital - Travel time patient - Waiting time patient
Centralisation of care: a necessity in the Netherlands (Wijsman, 2013)	Vision on the centralisation in the urologists discipline	- Change in work for medical specialist - Sustainability in strategic position hospital
Centralisation of acute obstetric care in the Netherlands: a qualitative study to explore the experiences of stakeholders with adaptations in organisation of care (van den Berg et al., 2021)	How are stakeholders involved in maternity care perceived and experienced the changes in the organization of centralizes maternity care	- Staff composition and nature of work - Shared decision making managing staff and medical staff
Centralisation of oncology care: the medical specialist must make the move (Honing & Marres, 2012)	Overview article giving the key framework on what is needed for centralisation	- Volume-quality relation - Amount of academic research - Financial implications
Beyond the centralisation hype: The relationship between volume and quality of care is overrated. (De Concentratiehype Voorbij | Medischcontact, 2012)	Advantages and disadvantages for stakeholder of centralisation	- Volume-quality relation - Staff composition and nature of work - Financial implications - Hospital strategic positioning - Care in multiple locations - Travel time patient
Centralisation of care and its effects on the quality of paediatrics in the Netherlands from the perspective of the child and parents. (K&Z & VSOP, 2016)	What does the literature say and what do children, young people and parents think are important concerns to consider for centralisation	- Volume-quality relation - Freedom of choice patient - Travel time - Waiting Time - Good integrated chain care
Centralisation of complex interventions could avoid more than 200 deaths (de Haas et al., 2020)	Study effect on mortality when centralising care, taking into account the increase in travel time.	- Travel time - Amount of academic research - Financial implications
Report on impact analysis centralisation interventions in patients with an AHA (Nederlandse Zorgautoriteit, 2022)	Impact analysis on centralisation effects in the case of congenital heart defect. Conduct after centralisation decision-making by ministry in 2021.	- Travel time / quality - Care in multiple locations - Change in staff composition - Usage if medical equipment / rooms - Financial implications - Training, education and research

Table 35 Dutch health care reports on centralisation and discussed parameters

Appendix F: Model run specifics for different experiments

Experiment	*Robustness*	*Average solving time (s)*	*Average iterations root relaxation*	*Solution gap (%)*
All max	N/A (deterministic)	0.03	48	0.0000
All min	N/A (deterministic)	0.02	106	
1 out 6	1 to 6	0.11	87	
2 out 6	1 to 15	0.16	79	
3 out 6	1 to 20	0.19	75	
Model details	*Rows*	*Columns*	*Nonzeros*	*Variables*
All max	789	300	1810	210 continuous, 90 integer (90 binary)
All min	789	300	1810	
1 out 6	789	300	1810	
2 out 6	789	300	1810	
3 out 6	789	300	1810	

Exp name	*Solving time (s)*	*Explored nodes*	*Details*
703	0.16	24	Optimize a model with 759 rows, 300 columns and 1550 nonzeros Variable types: 210 continuous, 90 integer (90 binary)
859	0.16	16	Optimize a model with 849 rows, 300 columns and 1730 nonzeros Variable types: 210 continuous, 90 integer (90 binary)
983	0.18	12	Optimize a model with 1135 rows, 300 columns and 1730 nonzeros. Variable types: 210 continuous, 90 integer (90 binary)
994	0.22	18	Optimize a model with 759 rows, 300 columns and 1550 nonzeros. Variable types: 210 continuous, 90 integer (90 binary)
1187	0.11	54	Optimize a model with 1029 rows, 300 columns and 2090 nonzeros Variable types: 210 continuous, 90 integer (90 binary)
'All max'	0.09	1	Optimize a model with 1569 rows, 300 columns and 3170w nonzeros Variable types: 210 continuous, 90 integer (90 binary)

Table 36: Model run specifics for different experiments

Appendix G: Overview of Distribution of Surgical Volumes for all unique outcomes

Type	*CZE*	*Anna*	*Elkerliek*	*MMC*	*MUMC*	*Maastro*	*Laurentius*	*SJG*	*VieCuri*	*Zuyderland*
Lung	0	0	0	0	150	0	0	0	0	112
Pancreas	97	0	0	0	0	0	0	0	0	0
Kidney	113	0	0	50	0	0	50	0	50	59
Cervical	36	0	0	0	0	0	24	0	0	0
Stomach	0	0	0	0	0	0	0	0	0	52
Oesopageal	88	0	0	0	0	0	0	0	0	0
Liver primary	0	0	0	72	126	0	0	0	0	0
Liver secondary	0	0	0	59	118	0	0	0	0	0
Bladder	52	0	0	0	50	0	0	0	0	51

Table 37: Results 1 out 6_1

Type	*CZE*	*Anna*	*Elkerliek*	*MMC*	*MUMC*	*Maastro*	*Laurentius*	*SJG*	*VieCuri*	*Zuyderland*
Lung	0	0	0	100	0	0	0	0	0	162
Pancreas	0	0	0	0	97	0	0	0	0	0
Kidney	113	0	0	0	50	0	50	0	50	58
Cervical	36	0	0	0	0	0	24	0	0	0
Stomach	0	0	0	0	0	0	0	0	0	52
Oesopageal	88	0	0	0	0	0	0	0	0	0
Liver primary	0	0	0	68	130	0	0	0	0	0
Liver secondary	0	0	0	50	127	0	0	0	0	0
Bladder	152	0	0	0	0	0	0	0	0	0

Table 38: Results 1 out 6_2

Type	*CZE*	*Anna*	*Elkerliek*	*MMC*	*MUMC*	*Maastro*	*Laurentius*	*SJG*	*VieCuri*	*Zuyderland*
Lung	0	0	0	115	0	0	0	0	0	147
Pancreas	0	0	0	0	97	0	0	0	0	0
Kidney	113	0	0	50	0	0	50	0	50	58
Cervical	36	0	0	0	0	0	24	0	0	0
Stomach	0	0	0	0	0	0	0	0	0	52
Oesopageal	88	0	0	0	0	0	0	0	0	0
Liver primary	0	0	0	0	198	0	0	0	0	0
Liver secondary	0	0	0	59	118	0	0	0	0	0
Bladder	152	0	0	0	0	0	0	0	0	0

Table 39: Results 1 out 6_3 , 2 out 6_2 and 2 out 6_3

Type	CZE	Anna	Elkerliek	MMC	MUMC	Maastro	Laurentius	SJG	VieCuri	Zuyderland
Lung	0	0	0	0	100	0	0	0	0	162
Pancreas	0	0	0	0	97	0	0	0	0	0
Kidney	113	0	0	0	50	0	50	0	50	58
Cervical	36	0	0	0	0	0	0	0	24	0
Stomach	0	0	0	0	0	0	0	0	0	52
Oesopageal	88	0	0	0	0	0	0	0	0	0
Liver primary	0	0	0	198	0	0	0	0	0	0
Liver secondary	0	0	0	0	177	0	0	0	0	0
Bladder	152	0	0	0	0	0	0	0	0	0

Table 40: Results 1 out 6_4 , 2 out 6_4 and 2 out 6_5

Type	CZE	Anna	Elkerliek	MMC	MUMC	Maastro	Laurentius	SJG	VieCuri	Zuyderland
Lung	0	0	0	0	128	0	0	0	0	134
Pancreas	0	0	0	0	97	0	0	0	0	0
Kidney	113	0	0	0	0	0	0	0	109	100
Cervical	36	0	0	0	0	0	24	0	0	0
Stomach	0	0	0	0	0	0	0	0	0	52
Oesopageal	88	0	0	0	0	0	0	0	0	0
Liver primary	0	0	0	198	0	0	0	0	0	0
Liver secondary	0	0	0	0	177	0	0	0	0	0
Bladder	152	0	0	0	0	0	0	0	0	0

Table 41: Results 1 out 6_5, 2 out 6_6 , 2 out 6_7 and 3 out 6_2-8

Type	CZE	Anna	Elkerliek	MMC	MUMC	Maastro	Laurentius	SJG	VieCuri	Zuyderland
Lung	50	0	0	50	50	0	50	0	0	62
Pancreas	0	0	0	0	97	0	0	0	0	0
Kidney	113	0	0	50	50	0	0	0	50	58
Cervical	60	0	0	0	0	0	0	0	0	0
Stomach	52	0	0	0	0	0	0	0	0	0
Oesopageal	88	0	0	0	0	0	0	0	0	0
Liver primary	0	0	0	72	126	0	0	0	0	0
Liver secondary	0	0	0	59	118	0	0	0	0	0
Bladder	67	0	0	0	0	0	0	0	0	86

Table 42: Results norm all min

Type	*CZE*	*Anna*	*Elkerliek*	*MMC*	*MUMC*	*Maastro*	*Laurentius*	*SJG*	*VieCuri*	*Zuyderland*
Lung	79	0	0	50	0	0	59	0	0	74
Pancreas	0	0	0	0	97	0	0	0	0	0
Kidney	113	0	0	50	50	0	0	0	50	58
Cervical	36	0	0	0	0	0	0	0	24	0
Stomach	52	0	0	0	0	0	0	0	0	0
Oesopageal	88	0	0	0	0	0	0	0	0	0
Liver primary	0	0	0	72	126	0	0	0	0	0
Liver secondary	0	0	0	59	118	0	0	0	0	0
Bladder	66	0	0	0	0	0	0	0	0	86

Table 43: Results 3 out 6_2

Type	*CZE*	*Anna*	*Elkerliek*	*MMC*	*MUMC*	*Maastro*	*Laurentius*	*SJG*	*VieCuri*	*Zuyderland*
Lung	0	0	0	50	50	0	53	0	0	109
Pancreas	0	0	0	0	97	0	0	0	0	0
Kidney	113	0	0	50	50	0	0	0	50	59
Cervical	36	0	0	0	0	0	0	0	0	24
Stomach	0	0	0	0	0	0	0	0	0	52
Oesopageal	88	0	0	0	0	0	0	0	0	0
Liver primary	0	0	0	0	198	0	0	0	0	0
Liver secondary	0	0	0	110	66	0	0	0	0	0
Bladder	152	0	0	0	0	0	0	0	0	0

Table 44: Results 2 out 6_1

Type	*CZE*	*Anna*	*Elkerliek*	*MMC*	*MUMC*	*Maastro*	*Laurentius*	*SJG*	*VieCuri*	*Zuyderland*
Lung	0	0	0	141	0	0	0	0	0	121
Pancreas	0	0	0	0	97	0	0	0	0	0
Kidney	122	0	0	0	0	0	0	0	100	100
Cervical	40	0	0	0	0	0	20	0	0	0
Stomach	52	0	0	0	0	0	0	0	0	0
Oesopageal	88	0	0	0	0	0	0	0	0	0
Liver primary	0	0	0	0	198	0	0	0	0	0
Liver secondary	0	0	0	59	118	0	0	0	0	0
Bladder	102	0	0	0	0	0	0	0	0	50

Table 45: Results 3 out 6_1

Scenario	Patient				
	Travel time	Waiting time	Freedom of choice	Quality of surgery [1]	Integral care pathway
1 '703'	**Lung** is only provided in the southern located hospitals (Zuyderland, MUMC). This would lead to an increase in travel burden for CZE/MMC patients. **Pancreas** only in CZE, leads to increase in travel burden for patients that would otherwise go to MUMC. **Stomach** only in Zuyderland, CZE patient population will face increased travel burden. **Oesophageal** only in CZE, Zuyderland patient population will face increased travel burden.	Higher volumes of surgeries per can positively impact waiting times for patients. Hospitals can manage their resources and staff more efficiently. For this scenario this is expected for **Lung**, **Pancreas**, **Cervical** as these have significant concentration and/or all surgical care for these types is only at one hospital. For **Stomach & Oesophageal** the efficiency is negatively affected because the surgeries are divided between two hospitals. This could influence the waiting time.	Hospitals providing surgeries for a certain type: - Lung 5 -> 2 - Pancreas 2 -> 1 - Kidney 7 -> 5 - Cervical 8 -> 2 - Stomach 2 -> 1 - Oesophageal 2 -> 1 - Liver primary 2 -> 2 - Liver secondary 2 -> 2 - Bladder 4 -> 3 Total care shift was 703, which means that 25% of patients would get their surgery at another hospital compared to the current allocation.	Increased values for all types are increased to volumes expected to increase quality of surgery in terms of mortality. **Pancreas** has more mortality-decrease potential but insufficient volumes in the OncoZON region to further concentrate	**Referral structures are needed for:** **Lung** from CZE/MMC to Zuyderland/MUMC. **Pancreas** from MUMC to CZE. **Kidney** from MUMC to Laurentius/MMC. For **Cervical** Anna/Elkerliek/MUMC/SJG/ Viecuri/Zuyderland to CZE/Laurentius. **Stomach** from CZE to Zuyderland. **Oesophageal** from Zuyderland to CZE. **Bladder** from CZE and VieCuri to MUMC/ Zuyderland. *Bladder remains provided in CZE, but it 'shares' volume to other hospitals for meeting the 50 norm.*
2 '859'	**Pancreas** only in MUMC, leads to increase in travel burden for CZE patients. **Stomach** only in Zuyderland, CZE patients will face increased travel burden. **Oesophageal** only in CZE, Zuyderland patients will face increased travel burden. **Bladder** is only in CZE, increased travel burden for MUMC/VieCuri/Zuyderland patients.	Higher volumes of surgeries per can positively impact waiting times for patients. Hospitals can manage their resources and staff more efficiently. For this scenario this is expected for **Lung**, **Pancreas**, **Cervical and** as these have significant concentration and/or all surgical care for these types is only at one hospital. For **Stomach & Oesophageal** the efficiency is negatively affected because the surgeries are divided between two hospitals. This could influence the waiting time.	Hospitals providing surgeries for a certain type: - Lung 5 -> 2 - Pancreas 2 -> 1 - Kidney 7 -> 5 - Cervical 8 -> 2 - Stomach 2 -> 1 - Oesophageal 2 -> 1 - Liver primary 2 -> 2 - Liver secondary 2 -> 2 - Bladder 4 -> 1 Total care shift was 859, which means that 30.5% of patients would get their surgery at another hospital compared to the current allocation.	Increased values for all types are increased to volumes expected to increase quality of surgery in terms of mortality. **Pancreas** has more mortality-decrease potential but insufficient volumes in the OncoZON region to further concentrate	**Referral structures are needed for:** **Lung** from CZE to MMC and from MUMC to Zuyderland. **Pancreas** from CZE to MUMC. **Kidney** from MMC to Laurentius/MUMC. For **Cervical** Anna/Elkerliek/MUMC/SJG/ Viecuri/Zuyderland to CZE/Laurentius. **Stomach** from CZE to Zuyderland. **Oesophageal** from Zuyderland to CZE. **Bladder** from MUMC/VieCuri/Zuyderland to CZE.
3 '983'	**Pancreas** only in MUMC, leads to increase in travel burden for CZE patients. **Stomach** only in Zuyderland, CZE patients will face increased travel burden. **Oesophageal** only in CZE,	Higher volumes of surgeries per can positively impact waiting times for patients. Hospitals can manage their resources and staff more efficiently. For this scenario this is expected for **Lung**, **Pancreas**,	Hospitals providing surgeries for a certain type: - Lung 5 -> 2 - Pancreas 2 -> 1 - Kidney 7 -> 5 - Cervical 8 -> 2	Increased values for all types are increased to volumes expected to increase quality of surgery in terms of mortality. **Pancreas** has more mortality-decrease potential but insufficient volumes in the	**Referral structures are needed for:** **Lung** from CZE/MMC to Zuyderland/MUMC . **Pancreas** from CZE to MUMC. **Kidney** from MUMC/Elkerliek to CZE/Laurentius/MMC/VieCuri/

	Zuyderland patients will face increased travel burden**. Liver primary** only in MUMC, increased burden for MMC patients. **Bladder** is only in CZE, increased travel burden for MUMC/VieCuri/Zuyderland patients	**Cervical and Bladder and Liver** as these have significant concentration and/or all surgical care for these types is only at one hospital. For **Stomach & Oesophageal** the efficiency is negatively affected because the surgeries are divided between two hospitals. This could influence the waiting time.	- Stomach 2 -> 1 - Oesophageal 2 -> 1 - Liver primary 2 -> 1 - Liver secondary 2 -> 2 - Bladder 4 -> 1 Total care shift was 983, which means that 34.9% of patients would get their surgery at another hospital compared to the current allocation.	OncoZON region to further concentrate	Zuyderland . For **Cervical** Anna/Elkerliek/MUMC/SJG/ Viecuri/Zuyderland to CZE/Laurentius. **Stomach** from CZE to Zuyderland. **Oesophageal** from Zuyderland to CZE. **Bladder** from MUMC/VieCuri/Zuyderland to CZE. Liver primary from MMC to MUMC.
4 '994'	**Pancreas** only in MUMC, leads to increase in travel burden for CZE patients. **Stomach & Oesophageal** only in CZE, Zuyderland patients will face increased travel burden. **Liver primary** only in MUMC, increased burden for MMC patients.	Higher volumes of surgeries per can positively impact waiting times for patients. Hospitals can manage their resources and staff more efficiently. For this scenario this is expected for **Lung**, **Pancreas**, **Kidney**, **Cervical, Stomach, Oesophageal, Bladder and Liver primary** as these have significant concentration and/or all surgical care for these types is only at one hospital.	Hospitals providing surgeries for a certain type: - Lung 5 -> 2 - Pancreas 2 -> 1 - Kidney 7 -> 3 - Cervical 8 -> 2 - Stomach 2 -> 1 - Oesophageal 2 -> 1 - Liver primary 2 -> 1 - Liver secondary 2 -> 2 - Bladder 4 -> 2 Total care shift was 994, which means that 35.3% of patients would get their surgery at another hospital compared to the current allocation.	Increased values for all types are increased to volumes expected to increase quality of surgery in terms of mortality. **Pancreas** has more mortality-decrease potential but insufficient volumes in the OncoZON region to further concentrate	**Lung** from CZE to MMC and from MUMC to Zuyderland. **Pancreas** from CZE to MUMC. **Kidney** from MUMC/Elkerliek/Laurentius/ MMC to CZE/VieCuri/ Zuyderland . For **Cervical** Anna/Elkerliek/MUMC/SJG/ Viecuri/Zuyderland to CZE/Laurentius. **Stomach** & **Oesophageal** from Zuyderland to CZE. **Bladder** from MUMC/VieCuri to CZE/Zuyderland. **Liver primary** from MMC to MUMC.
5 '1187'	**Lung** is only provided in the southern located hospitals (Zuyderland, MUMC). This would lead to an increase in travel burden for CZE/MMC patients. **Pancreas** only in MUMC, leads to increase in travel burden for CZE patients. . **Stomach** only in Zuyderland, CZE patients will face increased travel burden. **Oesophageal** only in CZE, Zuyderland patients will face increased travel burden. **Liver primary** only in MMC, increased burden for MUMC patients. **Liver secondary** only in MUMC,	Higher volumes of surgeries per can positively impact waiting times for patients. Hospitals can manage their resources and staff more efficiently. For this scenario this is expected for **Lung**, **Pancreas**, **Cervical, Bladder, Liver primary and liver secondary** as these have significant concentration and/or all surgical care for these types is only at one hospital. For **Stomach & Oesophageal** the efficiency is negatively affected because the surgeries are divided between two	Hospitals providing surgeries for a certain type: - Lung 5 -> 2 - Pancreas 2 -> 1 - Kidney 7 -> 5 - Cervical 8 -> 2 - Stomach 2 -> 1 - Oesophageal 2 -> 1 - Liver primary 2 -> 1 - Liver secondary 2 -> 1 - Bladder 4 -> 1 Total care shift was 1187, which means that 42.2% of patients would get their surgery at another	Increased values for all types are increased to volumes expected to increase quality of surgery in terms of mortality. **Pancreas** has more mortality-decrease potential but insufficient volumes in the OncoZON region to further concentrate	**Lung** from CZE/MMC to Zuyderland/MUMC. . **Pancreas** from CZE to MUMC. **Kidney** from Elkerliek/MMC to CZE/VieCuri/ Zuyderland/Laurentius/MUMC . For **Cervical** Anna/Elkerliek/ MUMC/SJG/ Laurentius/Zuyderland to CZE/VieCuri. **Stomach** from CZE to Zuyderland. **Oesophageal** from Zuyderland to CZE. . **Liver primary** from MUMC to MMC. **Liver secondary** from MMC to MUMC **Bladder** from MUMC/VieCuri/Zuyderland to CZE

	increased burden for MMC patients. **Bladder** is only in CZE, increased travel burden for MUMC/VieCuri/Zuyderland patients	hospitals. This could influence the waiting time.	hospital compared to the current allocation.		
6 'all max'	**Lung** is only provided in the southern located hospitals (Zuyderland, MUMC). This would lead to an increase in travel burden for CZE/MMC patients. **Pancreas** only in MUMC, leads to increase in travel burden for CZE patients. **Cervical** only in CZE, leading to increase burden for southern patients. **Stomach** only in Zuyderland, CZE patients will face increased travel burden. **Oesophageal** only in CZE, Zuyderland patients will face increased travel burden. **Liver primary** only in MMC, increased burden for MUMC patients. **Liver secondary** only in MUMC, increased burden for MMC patients. **Bladder** is only in CZE, increased travel burden for MUMC/VieCuri/Zuyderland patients	Higher volumes of surgeries per can positively impact waiting times for patients. Hospitals can manage their resources and staff more efficiently. For this scenario this is expected for **Lung**, **Pancreas**, **Kidney, Cervical, Bladder, Liver primary and liver secondary** as these have significant concentration and/or have only one location left so all surgical care is centred at one hospital. For **Stomach & Oesophageal** the efficiency is negatively affected because the surgeries are divided between two hospitals. This could influence the waiting time.	Hospitals providing surgeries for a certain type: - Lung 5 -> 2 - Pancreas 2 -> 1 - Kidney 7 -> 3 - Cervical 8 -> 1 - Stomach 2 -> 1 - Oesophageal 2 -> 1 - Liver primary 2 -> 1 - Liver secondary 2 -> 1 - Bladder 4 -> 1 Total care shift was 1311, which means that 46.6% of patients would get their surgery at another hospital compared to the current allocation.	Increased values for all types are increased to volumes expected to increase quality of surgery in terms of mortality. **Pancreas** has more mortality-decrease potential but insufficient volumes in the OncoZON region to further concentrate	**Lung** from CZE/MMC to Zuyderland/MUMC. . **Pancreas** from CZE to MUMC. **Kidney** from MUMC/Elkerliek/Laurentius/ MMC to CZE/VieCuri/ Zuyderland. For **Cervical** Anna/Elkerliek/ MUMC/SJG/ Laurentius/Zuyderland/VieCuri to CZE. **Stomach** from CZE to Zuyderland. **Oesophageal** from Zuyderland to CZE. **Liver primary** from MUMC to MMC. **Liver secondary** from MMC to MUMC **Bladder** from MUMC/VieCuri/Zuyderland to CZE

Table 46 : Description of the most important effects on the parameter related to the patient

[1] *Description and references of the cut-off values can be found in Appendix J*

Scenario	Hospital system				
	Resource usage	Revenue implications[2,3]	Portfolio – care volume[3]	Portfolio – care type	Sustainability
1 '703'	**CZE:** IC +25%, OR +4,3%, KL +7,1% **MUMC:** OR +1,2%, KL +6,7% **Zuyderland:** OR +18,8%, KL +19,9%	CZE: € 240.206,00 (+4,1%) Elkerliek: - € 75.412,00 (-100%) Anna & SJG: -€ 11.200,00 (-100%) MMC: -€ 271.176,00 (-7,6%) MUMC: € 189.024,00 (+2,5%) Laurentius: € 7.400,00 (+0,9%) VieCuri: -€ 472.012,00 (-47,5%) Zuyderland: € 448.894,00 (+14,5%) **MAD: 39.1%**	**Lung**: high increase for MUMC 43 to 150 (+249%) and Zuyderland 74 to 112 (+51%). **Pancreas**: high increase for CZE 53 to 97 (+83%). **Oesophageal**: high increase for CZE 52 to 88 (+69%) **MAD: 10.3%**	CZE and MMC stop providing **Lung** surgery. MUMC stops providing **Pancreas** surgery. MUMC stops providing **Kidney** surgery. VieCuri stops providing bladder surgery. Separation of **Oesophageal & Stomach** in CZE and Zuyderland is also not preferable, both care pathways are similar and provide cross-type expertise that is now separated.	**Anna/Elkerliek/SJG** will completely stop providing highly complex cancer surgery. Because their volumes were already low it will likely not have big influence on their strategic position. **VieCuri & Laurentius** both have low volumes for highly complex cancer surgery, so will be the first to lose these types in case of further concentration.
2 '859'	**CZE:** IC +25%, OR +1,6% **MMC:** IC +14,4%, OR +4,5%, KL +25% **MUMC** IC +9,5% , OR +3,1%, KL +2,2% **Zuyderland:** OR +6%, KL +9,7% **Bladder** makes use of robotic surgery, increase of volume at CZE (+103,3%) needs additional robot availability.	CZE: € 662.235,00 (+11,2%) Elkerliek: - € 75.412,00 (-100%) Anna & SJG: -€ 11.200,00 (-100%) MMC: -€ 23.173,00 (-0,65%) MUMC: € 44.342,00 (+0,58%) Laurentius: € 7.400,00 (+0,9%) VieCuri: -€ 472.012,00 (-47,5%) Zuyderland: -€ 107.855,00(-3,5%) **MAD: 24.9%**	**Lung**: high increase for MMC 43 to 100 (+132%) and Zuyderland 74 to 162 (+119%). **Pancreas**: high increase for MUMC 43 to 97 (+125%). **Oesophageal**: high increase for CZE 52 to 88 (+69%). **Bladder** high increase for CZE 66 to 152 (+130%) **MAD: 17.7%**	CZE and MUMC stop providing **Lung** surgery. MUMC stops providing **Pancreas** surgery. MUMC stops providing **Kidney** surgery. Separation of **Oesophageal & Stomach** in CZE and Zuyderland is also not preferable, both care pathways are similar and provide cross-type expertise that is now separated. **Bladder** is not provided in MUMC/VieCuri/Zuyderland anymore.	**Anna/Elkerliek/SJG** will completely stop providing highly complex cancer surgery. Because their volumes were already low it will likely not have big influence on their strategic position. **VieCuri & Laurentius** both have low volumes for highly complex cancer surgery, so will be the first to lose these types in case of further concentration.
3 '983'	**CZE:** IC +23,8%, OR +1,6% **MMC:** OR +1,1%, KL +20,9% **MUMC** IC +20,8% , OR +7,6%, KL +8,1% **Zuyderland:** KL +2,1% **Bladder** makes use of robotic surgery, increase of volume at CZE (+103,3%) needs additional robot availability.	CZE: € 662.235,00 (+11,2%) Elkerliek: - € 75.412,00 (-100%) Anna & SJG: -€ 11.200,00 (-100%) MMC: -€ 584.059,00 (-16,5%) MUMC: € 761.813,00 (+10,1%) Laurentius: € 7.400,00 (+0,9%) VieCuri: -€ 472.012,00 (-47,5%) Zuyderland: -€ 264.440,00(-8,5%) **MAD: 44.8%**	**Lung**: high increase for MMC 43 to 115 (+167%) and Zuyderland 74 to 147 (+99%). **Pancreas**: high increase for MUMC 43 to 97 (+125%). **Oesophageal**: high increase for CZE 52 to 88 (+69%). **Liver primary**: high increase for MUMC 72 to 198 (+175%). **Bladder** high increase for CZE 66 to 152 (+130%) **MAD: 17.9%**	CZE and MUMC stop providing **lung** surgery. CZE stops providing **Pancreas** surgery. MUMC stops providing **Kidney** surgery. Separation of **Oesophageal & Stomach** in CZE and Zuyderland is also not preferable, both care pathways are similar and provide cross-type expertise that is now separated. No **Liver primary** in MMC. **Bladder** is not provided in MUMC/VieCuri/Zuyderland anymore.	**Anna/Elkerliek/SJG** will completely stop providing highly complex cancer surgery. Because their volumes were already low it will likely not have big influence on their strategic position. **VieCuri & Laurentius** both have low volumes for highly complex cancer surgery, so will be the first to lose these types in case of further concentration.

4 '994'	**CZE:** IC +11,2% **MMC:** KL +25% **MUMC** IC +20,8% , OR +7,6%, KL +8,1% **VieCuri:** OR +13,8% **Zuyderland:** OR +16,6%, KL +12,5% **Bladder** makes use of robotic surgery, increase of volume at CZE (+54,5%) needs additional robot availability.	CZE: € 447.752,00 (+7,6%) Elkerliek: - € 75.412,00 (-100%) Anna & SJG: -€ 11.200,00 (-100%) MMC: -€ 835.295,00 (-23,5%) MUMC: € 761.813,00 (+10,1%) Laurentius-€ 560.050,00 (-71,4%) VieCuri: € 50.638,00 (+5,1%) Zuyderland: € 256.532,00(+8,3%) **MAD: 44.9%**	**Lung**: high increase for MMC 43 to 141 (+227%) and Zuyderland 74 to 121 (+63%). **Pancreas**: high increase for MUMC 43 to 97 (+125%). **Oesophageal**: high increase for CZE 52 to 88 (+69%). **Kidney:** high increase for VieCuri 50 to 100 (+100%) and Zuyderland 59 to 100 (+69%) **MAD: 13.3%**	CZE and MUMC stop providing **lung** surgery. CZE stops providing **Pancreas** surgery. MUMC/MMC stop providing **Kidney** surgery. **Oesophageal & Stomach** not in Zuyderland anymore. **Bladder** is not provided in MUMC/VieCuri anymore. No **liver primary** in MMC.	**Anna/Elkerliek/SJG** will completely stop providing highly complex cancer surgery. Because their volumes were already low it will likely not have big influence on their strategic position**. VieCuri & Laurentius** both have low volumes for highly complex cancer surgery, so will be the first to lose these types in case of further concentration.
5 '1187'	**CZE:** IC +23,8%, OR +1,6% **MMC:** IC +20,3%, OR +2,7% **MUMC** IC +7,4% , KL +14,8% **Zuyderland:** OR +6%, KL +9,7% **Bladder** makes use of robotic surgery, increase of volume at CZE (+103,3%) needs additional robot availability.	CZE: € 662.235,00 (+11,2%) Elkerliek: - € 75.412,00 (-100%) Anna & SJG: -€ 11.200,00 (-100%) MMC: € 614.447,00 (+17,3%) MUMC: -€ 593.278,00 (-7,9%) Laurentius: -€ 261.400,00 (-33,3%) VieCuri: -€ 203.212,00 (-20,4%) Zuyderland: -€ 107.855,00 (-3,5%) **MAD 35.3%**	**Lung**: high increase for MUMC 51 to 100 (+96%) and Zuyderland 74 to 162 (+119%). **Pancreas**: high increase for MUMC 43 to 97 (+125%). **Oesophageal**: high increase for CZE 52 to 88 (+69%). **Liver primary**: high increase for MMC 72 to 198 (+175%). **Bladder** high increase for CZE 66 to 152 (+130%) **MAD: 25.9%**	CZE and MMC stop providing **lung** surgery. CZE stops providing **Pancreas** surgery. MMC stops providing **Kidney** surgery. Separation of **Oesophageal & Stomach** in CZE and Zuyderland is also not preferable, both care pathways are similar and provide cross-type expertise that is now separated. . **Bladder** is not provided in MUMC/VieCuri anymore. No **Liver primary** in MUMC. No **liver secondary** in MMC.	**Anna/Elkerliek/SJG** will completely stop providing highly complex cancer surgery. Because their volumes were already low it will likely not have big influence on their strategic position**. VieCuri & Laurentius** both have low volumes for highly complex cancer surgery, so will be the first to lose these types in case of further concentration.
6 'all max'	**CZE:** IC +23,8%, OR +5,5%, KL +3,1% **MMC:** IC +20,3%, OR +2,7% **MUMC** IC +10,2% , KL +17,3% **VieCuri** OR +23,5% **Zuyderland:** OR +10,8%, KL +3,8% **Bladder** makes use of robotic surgery, increase of volume at CZE (+103,3%) needs additional robot availability.	CZE: € 931.035,00 (+15,8%) Elkerliek: - € 75.412,00 (-100%) Anna & SJG: -€ 11.200,00 (-100%) MMC: -€ 823.636,00 (-10,9%) MUMC: -€ 593.278,00 (-7,9%) Laurentius: -€ 784.050,00 (-100%) VieCuri: € 144.715,00 (+14,5%) Zuyderland: € 38.879,00 (+1,3%) **MAD: 45.6%**	**Lung**: high increase for MUMC 51 to 128 (+151%) and Zuyderland 74 to 134 (+81%). **Pancreas**: high increase for MUMC 43 to 97 (+125%). **Kidney:** high increase for VieCuri 50 to 109 (+118%) and Zuyderland 59 to 100 (+69%) **Oesophageal**: high increase for CZE 52 to 88 (+69%). **Liver primary**: high increase for MMC 72 to 198 (+175%). **Bladder** high increase for CZE 66 to 152 (+130%) **MAD: 27%**	CZE and MMC stop providing **lung** surgery. CZE stops providing **Pancreas** surgery. MMC/MUMC/Laurentius stop providing **Kidney** surgery. Separation of **Oesophageal & Stomach** in CZE and Zuyderland is also not preferable, both care pathways are similar and provide cross-type expertise that is now separated. **Bladder** is not provided in MUMC/VieCuri anymore. No **liver primary** in MUMC. No **liver secondary** in MMC.	**Anna/Elkerliek/SJG/Laurentius** will completely stop providing highly complex cancer surgery. Because their volumes were already low it will likely not have big influence on their strategic position, however for **Laurentius** a bigger impact is expected as their volumes are higher**. VieCuri** both has low volumes for highly complex cancer surgery, so will be the first to lose these types in case of further concentration.

Table 47: Description of the most important effects on the parameter related to the hospital system

[2] *description and calculation of these numbers can be found in Appendix K*

[3] *description and calculation of the Mean Absolute Deviation can be found in Appendix L*

Scenario	Medical profession		
	Composition	Academic research	(Re)training and education
1 '703'	**Lung** surgeons in MMC/CZE will have no surgical tasks anymore. **Oesophageal & Stomach** provided in different hospitals is inefficient as personnel has expertise for both types.	No **lung** surgery in CZE/MUMC stops academic research in this region, however it can stimulate academic research in the MUMC/Zuyderland region. **Oesophageal & Stomach** provided in different hospitals hinders academic research. **Pancreas** in CZE could stimulate academic research.	Most (supporting) medical personnel is trained for different high complex cancer surgeries so is versatile and able to provide care for different cancer types. There could be case specific case managers for specific types that need to retrained.
2 '859'	CZE: The increase in **bladder** surgery asks for more surgeon availability. **Lung** surgeons in MUMC/CZE will have no surgical tasks anymore. **Oesophageal & Stomach** provided in different hospitals is inefficient as personnel has expertise for both types. CZE**: Pancreas** surgeons could focus more on **Oesophageal**	**Oesophageal & Stomach** provided in different hospitals hinders academic research. **Pancreas** in MUMC could stimulate academic research.	Most (supporting) medical personnel is trained for different high complex cancer surgeries so is versatile and able to provide care for different cancer types. There could be case specific case managers for specific types that need to retrained.
3 '983'	CZE: The increase in **bladder** surgery asks for more surgeon availability. **Lung** surgeons in MUMC/CZE will have no surgical tasks anymore. **Oesophageal & Stomach** provided in different hospitals is inefficient as personnel has expertise for both types. CZE**: Pancreas** surgeons could focus more on **Oesophageal**	**Oesophageal & Stomach** provided in different hospitals hinders academic research. **Pancreas** in MUMC could stimulate academic research.	Most (supporting) medical personnel is trained for different high complex cancer surgeries so is versatile and able to provide care for different cancer types. There could be case specific case managers for specific types that need to retrained.
4 '994'	CZE: The increase in **bladder** surgery asks for more surgeon availability. **Lung** surgeons in MUMC/CZE will have no surgical tasks anymore. CZE**: Pancreas** surgeons could focus more on **Oesophageal.**	**Oesophageal & Stomach** concentrated in CZE would increase the amount of academic research. **Pancreas** in MUMC could stimulate academic research.	Most (supporting) medical personnel is trained for different high complex cancer surgeries so is versatile and able to provide care for different cancer types. There could be case specific case managers for specific types that need to retrained.
5 '1187'	CZE: The increase in **bladder** surgery asks for more surgeon availability. **Lung** surgeons in MMC/CZE will have no surgical tasks anymore. **Oesophageal & Stomach** provided in different hospitals is inefficient as personnel has expertise for both types. CZE**: Pancreas** surgeons could focus more on **Oesophageal**	No **lung** surgery in CZE/MUMC stops academic research in this region, however it can stimulate academic research in the MUMC/Zuyderland region. **Oesophageal & Stomach** provided in different hospitals hinders academic research. **Pancreas** in MUMC could stimulate academic research.	Most (supporting) medical personnel is trained for different high complex cancer surgeries so is versatile and able to provide care for different cancer types. There could be case specific case managers for specific types that need to retrained.
6 'all max'	CZE: The increase in **bladder** surgery asks for more surgeon availability. **Lung** surgeons in MMC/CZE will have no surgical tasks anymore. **Oesophageal & Stomach** provided in different hospitals is inefficient as personnel has expertise for both types. CZE**: Pancreas** surgeons could focus more on **Oesophageal. Only cervical surgeries in CZE,** so other hospitals surgeons stop performing cervical cancer surgeries.	No **lung** surgery in CZE/MUMC stops academic research in this region, however it can stimulate academic research in the MUMC/Zuyderland region. **Oesophageal & Stomach** provided in different hospitals hinders academic research. **Pancreas** in MUMC could stimulate academic research.	Most (supporting) medical personnel is trained for different high complex cancer surgeries so is versatile and able to provide care for different cancer types. There could be case specific case managers for specific types that need to retrained.

Table 48: Description of the most important effects on the parameter related to the medical profession

Appendix J: Research into the cut-off values for decrease of mortality.

Type	*Volume to where decrease of mortality persists (surgeries per year)*	*Source*
Lung	100	SiRM report included this tumour type and discussed the cut-off values for decrease of mortality with increase of volumes (de Haas et al., 2020b) .
Pancreas	300	SiRM report included this tumour type and discussed the cut-off values for decrease of mortality with increase of volumes (de Haas et al., 2020b) .
Kidney	50+	(Hsu et al., 2017) Influence of hospital volume on nephrectomy mortality and complications: a systematic review and meta-analysis stratified by surgical type
Cervical	Not specified	
Stomach	50	SiRM report included this tumour type and discussed the cut-off values for decrease of mortality with increase of volumes (de Haas et al., 2020b) .
Oesophageal	50	SiRM report included this tumour type and discussed the cut-off values for decrease of mortality with increase of volumes (de Haas et al., 2020b) .
Liver (primary)	100+	SiRM report included this tumour type and discussed the cut-off values for decrease of mortality with increase of volumes (de Haas et al., 2020b) .
Liver (secondary)	100+	SiRM report included this tumour type and discussed the cut-off values for decrease of mortality with increase of volumes (de Haas et al., 2020b) .
Bladder	50	SiRM report included this tumour type and discussed the cut-off values for decrease of mortality with increase of volumes (de Haas et al., 2020b) .

Table 49: Volumes to which evidence proofs decrease in mortality occurs is expected

Appendix K: Calculation of the changes in revenue for different allocations

To calculate the changes in revenue, the current revenue from the current surgical volumes for the included types or compared to the revenue from the models allocation. For the estimation the "Passing price of an operation" (*passantentarief*) of CZE hospital are used. Only the price of the surgery itself is included for this calculation. Table 50 show the prices for surgery and Table 51 shows the current allocations revenue and this value is compared with the new allocation.

Type	*Price per surgery*
Lung	€ 10.439,00
Pancreas	€ 17.243,00
Kidney	€ 10.453,00
Cervical	€ 11.200,00
Stomach	€ 13.345,00
Oesophageal	€ 20.427,00
Liver (primary)	€ 21.019,00
Liver (secondary)	€ 21.019,00

Table 50: Price per surgery type

Hospital	*Current revenue*
CZE	€ 5.903.522,00
Anna	€ 11.200,00
Elkerliek	€ 75.412,00
MMC	€ 3.547.315,00
MUMC	€ 7.552.762,00
Laurentius	€ 784.050,00
SJG	€ 11.200,00
VieCuri	€ 994.662,00

Table 51: Total current revenue per hospital

Appendix L: Calculation of the Mean Absolute Deviation (MAD)

The MAD is a measure of the average distance between each data point and the mean of the data set. It is calculated by taking the absolute value of the difference between each data point and the mean, adding up all these absolute differences, and then dividing by the total number of data points. The formula for MAD is:

$$MAD = \sum |Xi - \bar{X}|/n$$

With

$\sum$ is the sum of all absolute differences

Xi is the value of the i-th data point

$\bar{X}$ is the mean of all data points

n is the total number of data points

Appendix M: Allocation outcomes of the sensitivity analysis

Type	*CZE*	*Anna*	*Elkerliek*	*MMC*	*MUMC*	*Maastro*	*Laurentius*	*SJG*	*VieCuri*	*Zuyderland*
Lung	0	0	0	0	0	0	0	0	0	170
Pancreas	0	0	0	0	63	0	0	0	0	0
Kidney	109	0	0	0	0	0	0	0	50	50
Cervical	39	0	0	0	0	0	0	0	0	0
Stomach	34	0	0	0	0	0	0	0	0	0
Oesopageal	57	0	0	0	0	0	0	0	0	0
Liver primary	0	0	0	72	57	0	0	0	0	0
Liver secondary	0	0	0	0	115	0	0	0	0	0
Bladder	99	0	0	0	0	0	0	0	0	0

Table 52: Results '703' -35% demand

Type	*CZE*	*Anna*	*Elkerliek*	*MMC*	*MUMC*	*Maastro*	*Laurentius*	*SJG*	*VieCuri*	*Zuyderland*
Lung	0	0	0	0	0	0	0	0	0	196
Pancreas	0	0	0	0	73	0	0	0	0	0
Kidney	91	0	0	0	50	0	0	0	50	50
Cervical	25	0	0	0	20	0	0	0	0	0
Stomach	59	0	0	0	0	0	0	0	0	0
Oesopageal	66	0	0	0	0	0	0	0	0	0
Liver primary	0	0	0	70	79	0	0	0	0	0
Liver secondary	0	0	0	59	74	0	0	0	0	0
Bladder	64	0	0	0	50	0	0	0	0	0

Table 53: Results '703' -25% demand

Type	*CZE*	*Anna*	*Elkerliek*	*MMC*	*MUMC*	*Maastro*	*Laurentius*	*SJG*	*VieCuri*	*Zuyderland*
Lung	0	0	0	0	104	0	0	0	0	118
Pancreas	0	0	0	0	82	0	0	0	0	0
Kidney	113	0	0	51	0	0	0	0	50	59
Cervical	51	0	0	0	0	0	0	0	0	0
Stomach	45	0	0	0	0	0	0	0	0	0
Oesopageal	74	0	0	0	0	0	0	0	0	0
Liver primary	0	0	0	72	96	0	0	0	0	0
Liver secondary	0	0	0	59	92	0	0	0	0	0
Bladder	80	0	0	0	0	0	0	0	0	50

Table 54: Results '703' -15% demand

Type	CZE	Anna	Elkerliek	MMC	MUMC	Maastro	Laurentius	SJG	VieCuri	Zuyderland
Lung	100	0	0	0	100	0	0	0	0	101
Pancreas	61	0	0	0	50	0	0	0	0	0
Kidney	111	0	0	50	50	0	50	0	50	59
Cervical	22	0	0	0	0	0	20	0	28	0
Stomach	0	0	0	0	0	0	0	0	0	60
Oesopageal	50	0	0	0	0	0	0	0	0	51
Liver primary	0	0	0	102	126	0	0	0	0	0
Liver secondary	0	0	0	90	114	0	0	0	0	0
Bladder	119	0	0	0	56	0	0	0	0	0

Table 55: Results '703' +15% demand

Type	CZE	Anna	Elkerliek	MMC	MUMC	Maastro	Laurentius	SJG	VieCuri	Zuyderland
Lung	0	0	0	0	100	0	100	0	0	193
Pancreas	95	0	0	0	50	0	0	0	0	0
Kidney	113	0	50	50	50	0	110	0	50	59
Cervical	51	0	0	0	20	0	0	0	0	20
Stomach	79	0	0	0	0	0	0	0	0	0
Oesopageal	81	0	0	0	0	0	0	0	0	50
Liver primary	0	0	0	171	126	0	0	0	0	0
Liver secondary	0	0	0	59	207	0	0	0	0	0
Bladder	66	0	0	0	50	0	0	0	62	50

Table 56: Results '703' +25% demand

Type	CZE	Anna	Elkerliek	MMC	MUMC	Maastro	Laurentius	SJG	VieCuri	Zuyderland
Lung	149	0	0	0	100	0	0	0	0	105
Pancreas	59	0	0	0	71	0	0	0	0	0
Kidney	113	0	0	50	50	0	96	0	66	59
Cervical	36	0	0	0	20	0	0	0	26	0
Stomach	71	0	0	0	0	0	0	0	0	0
Oesopageal	56	0	0	0	0	0	0	0	0	62
Liver primary	0	0	0	141	126	0	0	0	0	0
Liver secondary	0	0	0	59	180	0	0	0	0	0
Bladder	106	0	0	0	50	0	0	0	0	50

Table 57: Results '703' +35% demand

Type	CZE	Anna	Elkerliek	MMC	MUMC	Maastro	Laurentius	SJG	VieCuri	Zuyderland
Lung	0	0	0	0	0	0	0	0	0	170
Pancreas	0	0	0	0	63	0	0	0	0	0
Kidney	109	0	0	0	0	0	0	0	50	50
Cervical	39	0	0	0	0	0	0	0	0	0
Stomach	34	0	0	0	0	0	0	0	0	0
Oesopageal	57	0	0	0	0	0	0	0	0	0
Liver primary	0	0	0	72	57	0	0	0	0	0
Liver secondary	0	0	0	0	115	0	0	0	0	0
Bladder	99	0	0	0	0	0	0	0	0	0

Table 58: Results ‘859’ -35% demand

Type	CZE	Anna	Elkerliek	MMC	MUMC	Maastro	Laurentius	SJG	VieCuri	Zuyderland
Lung	0	0	0	0	0	0	0	0	0	196
Pancreas	0	0	0	0	73	0	0	0	0	0
Kidney	91	0	0	0	50	0	0	0	50	50
Cervical	25	0	0	0	20	0	0	0	0	0
Stomach	59	0	0	0	0	0	0	0	0	0
Oesopageal	66	0	0	0	0	0	0	0	0	0
Liver primary	0	0	0	72	77	0	0	0	0	0
Liver secondary	0	0	0	59	74	0	0	0	0	0
Bladder	114	0	0	0	0	0	0	0	0	0

Table 59: Results ‘859’ -25% demand

Type	CZE	Anna	Elkerliek	MMC	MUMC	Maastro	Laurentius	SJG	VieCuri	Zuyderland
Lung	0	0	0	0	100	0	0	0	0	123
Pancreas	0	0	0	0	82	0	0	0	0	0
Kidney	113	0	0	50	0	0	0	0	50	60
Cervical	51	0	0	0	0	0	0	0	0	0
Stomach	45	0	0	0	0	0	0	0	0	0
Oesopageal	74	0	0	0	0	0	0	0	0	0
Liver primary	0	0	0	72	96	0	0	0	0	0
Liver secondary	0	0	0	59	92	0	0	0	0	0
Bladder	130	0	0	0	0	0	0	0	0	0

Table 60: Results ‘859’ -15% demand

Type	CZE	Anna	Elkerliek	MMC	MUMC	Maastro	Laurentius	SJG	VieCuri	Zuyderland
Lung	100	0	0	0	100	0	0	0	0	101
Pancreas	55	0	0	0	57	0	0	0	0	0
Kidney	113	0	0	50	50	0	50	0	50	57
Cervical	36	0	0	0	0	0	0	0	33	0
Stomach	0	0	0	0	0	0	0	0	0	60
Oesopageal	51	0	0	0	0	0	0	0	0	50
Liver primary	0	0	0	102	126	0	0	0	0	0
Liver secondary	0	0	0	82	121	0	0	0	0	0
Bladder	175	0	0	0	0	0	0	0	0	0

Table 61: Results '859' +15% demand

Type	CZE	Anna	Elkerliek	MMC	MUMC	Maastro	Laurentius	SJG	VieCuri	Zuyderland
Lung	0	0	0	0	100	0	100	0	0	127
Pancreas	53	0	0	0	67	0	0	0	0	0
Kidney	113	0	0	50	50	0	50	0	80	59
Cervical	36	0	0	0	20	0	0	0	20	0
Stomach	66	0	0	0	0	0	0	0	0	0
Oesopageal	57	0	0	0	0	0	0	0	0	52
Liver primary	0	0	0	122	126	0	0	0	0	0
Liver secondary	0	0	0	62	158	0	0	0	0	0
Bladder	191	0	0	0	0	0	0	0	0	0

Table 62: Results '859' +25% demand

Type	CZE	Anna	Elkerliek	MMC	MUMC	Maastro	Laurentius	SJG	VieCuri	Zuyderland
Lung	0	0	0	100	100	0	0	0	0	154
Pancreas	131	0	0	0	0	0	0	0	0	0
Kidney	113	0	0	50	50	0	96	0	66	59
Cervical	36	0	0	0	20	0	0	0	26	0
Stomach	71	0	0	0	0	0	0	0	0	0
Oesopageal	52	0	0	0	0	0	0	0	0	66
Liver primary	0	0	0	72	195	0	0	0	0	0
Liver secondary	0	0	0	71	168	0	0	0	0	0
Bladder	100	0	0	0	106	0	0	0	0	0

Table 63: Results '859' +35% demand

Type	*CZE*	*Anna*	*Elkerliek*	*MMC*	*MUMC*	*Maastro*	*Laurentius*	*SJG*	*VieCuri*	*Zuyderland*
Lung	0	0	0	0	0	0	0	0	0	170
Pancreas	0	0	0	0	63	0	0	0	0	0
Kidney	109	0	0	0	0	0	0	0	50	50
Cervical	39	0	0	0	0	0	0	0	0	0
Stomach	34	0	0	0	0	0	0	0	0	0
Oesopageal	57	0	0	0	0	0	0	0	0	0
Liver primary	0	0	0	0	129	0	0	0	0	0
Liver secondary	0	0	0	0	115	0	0	0	0	0
Bladder	99	0	0	0	0	0	0	0	0	0

Table 64: Results '983' -35% demand

Type	*CZE*	*Anna*	*Elkerliek*	*MMC*	*MUMC*	*Maastro*	*Laurentius*	*SJG*	*VieCuri*	*Zuyderland*
Lung	0	0	0	0	0	0	0	0	0	196
Pancreas	0	0	0	0	73	0	0	0	0	0
Kidney	91	0	0	0	50	0	0	0	50	50
Cervical	25	0	0	0	20	0	0	0	0	0
Stomach	59	0	0	0	0	0	0	0	0	0
Oesopageal	66	0	0	0	0	0	0	0	0	0
Liver primary	0	0	0	0	149	0	0	0	0	0
Liver secondary	0	0	0	59	74	0	0	0	0	0
Bladder	114	0	0	0	0	0	0	0	0	0

Table 65: Results '983' -25% demand

Type	*CZE*	*Anna*	*Elkerliek*	*MMC*	*MUMC*	*Maastro*	*Laurentius*	*SJG*	*VieCuri*	*Zuyderland*
Lung	0	0	0	105	0	0	0	0	0	118
Pancreas	0	0	0	0	82	0	0	0	0	0
Kidney	113	0	0	0	50	0	0	0	51	59
Cervical	51	0	0	0	0	0	0	0	0	0
Stomach	45	0	0	0	0	0	0	0	0	0
Oesopageal	74	0	0	0	0	0	0	0	0	0
Liver primary	0	0	0	0	168	0	0	0	0	0
Liver secondary	0	0	0	59	92	0	0	0	0	0
Bladder	130	0	0	0	0	0	0	0	0	0

Table 66: Results '983' -15% demand

Type	*CZE*	*Anna*	*Elkerliek*	*MMC*	*MUMC*	*Maastro*	*Laurentius*	*SJG*	*VieCuri*	*Zuyderland*
Lung	100	0	0	0	100	0	0	0	0	101
Pancreas	55	0	0	0	57	0	0	0	0	0
Kidney	111	0	0	50	50	0	50	0	50	59
Cervical	36	0	0	0	0	0	0	0	33	0
Stomach	0	0	0	0	0	0	0	0	0	60
Oesopageal	51	0	0	0	0	0	0	0	0	50
Liver primary	0	0	0	102	126	0	0	0	0	0
Liver secondary	0	0	0	82	121	0	0	0	0	0
Bladder	175	0	0	0	0	0	0	0	0	0

Table 67: Results '983' +15% demand

Type	*CZE*	*Anna*	*Elkerliek*	*MMC*	*MUMC*	*Maastro*	*Laurentius*	*SJG*	*VieCuri*	*Zuyderland*
Lung	0	0	0	0	100	0	100	0	0	127
Pancreas	53	0	0	0	67	0	0	0	0	0
Kidney	113	0	0	50	50	0	50	0	80	59
Cervical	36	0	0	0	20	0	0	0	20	0
Stomach	66	0	0	0	0	0	0	0	0	0
Oesopageal	52	0	0	0	0	0	0	0	0	57
Liver primary	0	0	0	100	148	0	0	0	0	0
Liver secondary	0	0	0	84	137	0	0	0	0	0
Bladder	191	0	0	0	0	0	0	0	0	0

Table 68: Results '983' +25% demand

Type	*CZE*	*Anna*	*Elkerliek*	*MMC*	*MUMC*	*Maastro*	*Laurentius*	*SJG*	*VieCuri*	*Zuyderland*
Lung	131	0	0	0	0	0	0	0	0	223
Pancreas	65	0	0	0	65	0	0	0	0	0
Kidney	113	0	0	50	50	0	96	0	66	59
Cervical	36	0	0	0	20	0	0	0	26	0
Stomach	71	0	0	0	0	0	0	0	0	0
Oesopageal	68	0	0	0	0	0	0	0	0	50
Liver primary	0	0	0	141	126	0	0	0	0	0
Liver secondary	0	0	0	94	145	0	0	0	0	0
Bladder	100	0	0	0	106	0	0	0	0	0

Table 69: Results '983' +35% demand

Type	CZE	Anna	Elkerliek	MMC	MUMC	Maastro	Laurentius	SJG	VieCuri	Zuyderland
Lung	0	0	0	0	0	0	0	0	0	170
Pancreas	0	0	0	0	63	0	0	0	0	0
Kidney	109	0	0	0	0	0	0	0	0	100
Cervical	39	0	0	0	0	0	0	0	0	0
Stomach	34	0	0	0	0	0	0	0	0	0
Oesopageal	57	0	0	0	0	0	0	0	0	0
Liver primary	0	0	0	0	129	0	0	0	0	0
Liver secondary	0	0	0	0	115	0	0	0	0	0
Bladder	99	0	0	0	0	0	0	0	0	0

Table 70: Results '994' -35% demand

Type	CZE	Anna	Elkerliek	MMC	MUMC	Maastro	Laurentius	SJG	VieCuri	Zuyderland
Lung	0	0	0	0	0	0	0	0	0	196
Pancreas	0	0	0	0	73	0	0	0	0	0
Kidney	141	0	0	0	0	0	0	0	100	0
Cervical	45	0	0	0	0	0	0	0	0	0
Stomach	59	0	0	0	0	0	0	0	0	0
Oesopageal	66	0	0	0	0	0	0	0	0	0
Liver primary	0	0	0	0	149	0	0	0	0	0
Liver secondary	0	0	0	59	74	0	0	0	0	0
Bladder	64	0	0	0	50	0	0	0	0	0

Table 71: Results '994' -25% demand

Type	CZE	Anna	Elkerliek	MMC	MUMC	Maastro	Laurentius	SJG	VieCuri	Zuyderland
Lung	0	0	0	105	0	0	0	0	0	118
Pancreas	0	0	0	0	82	0	0	0	0	0
Kidney	113	0	0	0	0	0	0	0	0	160
Cervical	51	0	0	0	0	0	0	0	0	0
Stomach	45	0	0	0	0	0	0	0	0	0
Oesopageal	74	0	0	0	0	0	0	0	0	0
Liver primary	0	0	0	0	168	0	0	0	0	0
Liver secondary	0	0	0	59	92	0	0	0	0	0
Bladder	130	0	0	0	0	0	0	0	0	0

Table 72: Results '994' -15% demand

Type	CZE	Anna	Elkerliek	MMC	MUMC	Maastro	Laurentius	SJG	VieCuri	Zuyderland
Lung	0	0	0	101	100	0	0	0	0	100
Pancreas	61	0	0	0	50	0	0	0	0	0
Kidney	124	0	0	0	0	0	114	0	132	0
Cervical	50	0	0	0	20	0	0	0	0	0
Stomach	60	0	0	0	0	0	0	0	0	0
Oesopageal	51	0	0	0	0	0	0	0	0	50
Liver primary	0	0	0	100	128	0	0	0	0	0
Liver secondary	0	0	0	59	145	0	0	0	0	0
Bladder	67	0	0	0	55	0	0	0	0	53

Table 73: Results '994' +15% demand

Type	CZE	Anna	Elkerliek	MMC	MUMC	Maastro	Laurentius	SJG	VieCuri	Zuyderland
Lung	0	0	0	0	127	0	100	0	0	100
Pancreas	53	0	0	0	67	0	0	0	0	0
Kidney	102	0	0	0	100	0	0	0	100	100
Cervical	36	0	20	0	20	0	0	0	0	0
Stomach	66	0	0	0	0	0	0	0	0	0
Oesopageal	59	0	0	0	0	0	0	0	0	50
Liver primary	0	0	0	110	138	0	0	0	0	0
Liver secondary	0	0	0	103	118	0	0	0	0	0
Bladder	80	0	0	0	0	0	0	0	61	50

Table 74: Results '994' +25% demand

Type	CZE	Anna	Elkerliek	MMC	MUMC	Maastro	Laurentius	SJG	VieCuri	Zuyderland
Lung	100	0	0	0	154	0	0	0	0	100
Pancreas	77	0	0	0	53	0	0	0	0	0
Kidney	113	0	0	0	0	0	114	0	107	100
Cervical	37	0	0	0	20	0	0	0	25	0
Stomach	71	0	0	0	0	0	0	0	0	0
Oesopageal	68	0	0	0	0	0	0	0	0	50
Liver primary	0	0	0	141	126	0	0	0	0	0
Liver secondary	0	0	0	106	133	0	0	0	0	0
Bladder	106	0	0	0	50	0	0	0	0	50

Table 75: Results '994' +35% demand

Type	CZE	Anna	Elkerliek	MMC	MUMC	Maastro	Laurentius	SJG	VieCuri	Zuyderland
Lung	0	0	0	0	0	0	0	0	0	170
Pancreas	0	0	0	0	63	0	0	0	0	0
Kidney	109	0	0	0	0	0	0	0	50	50
Cervical	39	0	0	0	0	0	0	0	0	0
Stomach	34	0	0	0	0	0	0	0	0	0
Oesopageal	57	0	0	0	0	0	0	0	0	0
Liver primary	0	0	0	0	129	0	0	0	0	0
Liver secondary	0	0	0	0	115	0	0	0	0	0
Bladder	99	0	0	0	0	0	0	0	0	0

Table 76: Results '1187' -35% demand

Type	CZE	Anna	Elkerliek	MMC	MUMC	Maastro	Laurentius	SJG	VieCuri	Zuyderland
Lung	0	0	0	0	0	0	0	0	0	196
Pancreas	0	0	0	0	73	0	0	0	0	0
Kidney	91	0	0	50	0	0	0	0	50	50
Cervical	25	0	0	0	20	0	0	0	0	0
Stomach	59	0	0	0	0	0	0	0	0	0
Oesopageal	66	0	0	0	0	0	0	0	0	0
Liver primary	0	0	0	0	149	0	0	0	0	0
Liver secondary	0	0	0	0	133	0	0	0	0	0
Bladder	114	0	0	0	0	0	0	0	0	0

Table 77: Results '1187' -25% demand

Type	CZE	Anna	Elkerliek	MMC	MUMC	Maastro	Laurentius	SJG	VieCuri	Zuyderland
Lung	0	0	0	123	0	0	0	0	0	100
Pancreas	0	0	0	0	82	0	0	0	0	0
Kidney	113	0	0	51	0	0	0	0	50	59
Cervical	51	0	0	0	0	0	0	0	0	0
Stomach	45	0	0	0	0	0	0	0	0	0
Oesopageal	74	0	0	0	0	0	0	0	0	0
Liver primary	0	0	0	0	168	0	0	0	0	0
Liver secondary	0	0	0	0	150	0	0	0	0	0
Bladder	130	0	0	0	0	0	0	0	0	0

Table 78: Results '1187' -15% demand

Type	CZE	Anna	Elkerliek	MMC	MUMC	Maastro	Laurentius	SJG	VieCuri	Zuyderland
Lung	100	0	0	0	101	0	0	0	0	100
Pancreas	53	0	0	0	58	0	0	0	0	0
Kidney	111	0	0	50	50	0	50	0	50	59
Cervical	36	0	0	0	0	0	0	0	33	0
Stomach	0	0	0	0	0	0	0	0	0	60
Oesopageal	51	0	0	0	0	0	0	0	0	50
Liver primary	0	0	0	100	128	0	0	0	0	0
Liver secondary	0	0	0	100	103	0	0	0	0	0
Bladder	175	0	0	0	0	0	0	0	0	0

Table 79: Results '1187' +15% demand

Type	CZE	Anna	Elkerliek	MMC	MUMC	Maastro	Laurentius	SJG	VieCuri	Zuyderland
Lung	0	0	0	0	100	0	100	0	0	127
Pancreas	64	0	0	0	57	0	0	0	0	0
Kidney	113	0	0	50	50	0	50	0	80	59
Cervical	36	0	0	0	20	0	0	0	20	0
Stomach	66	0	0	0	0	0	0	0	0	0
Oesopageal	57	0	0	0	0	0	0	0	0	52
Liver primary	0	0	0	122	126	0	0	0	0	0
Liver secondary	0	0	0	100	121	0	0	0	0	0
Bladder	191	0	0	0	0	0	0	0	0	0

Table 80: Results '1187' +25% demand

Type	CZE	Anna	Elkerliek	MMC	MUMC	Maastro	Laurentius	SJG	VieCuri	Zuyderland
Lung	135	0	0	0	0	0	0	0	0	219
Pancreas	63	0	0	0	68	0	0	0	0	0
Kidney	113	0	0	50	50	0	96	0	66	59
Cervical	36	0	0	0	20	0	0	0	26	0
Stomach	71	0	0	0	0	0	0	0	0	0
Oesopageal	68	0	0	0	0	0	0	0	0	50
Liver primary	0	0	0	141	127	0	0	0	0	0
Liver secondary	0	0	0	100	139	0	0	0	0	0
Bladder	100	0	0	0	106	0	0	0	0	0

Table 81: Results '1187' +35% demand

Type	*CZE*	*Anna*	*Elkerliek*	*MMC*	*MUMC*	*Maastro*	*Laurentius*	*SJG*	*VieCuri*	*Zuyderland*
Lung	0	0	0	0	0	0	0	0	0	170
Pancreas	0	0	0	0	63	0	0	0	0	0
Kidney	109	0	0	0	0	0	0	0	0	100
Cervical	39	0	0	0	0	0	0	0	0	0
Stomach	34	0	0	0	0	0	0	0	0	0
Oesopageal	57	0	0	0	0	0	0	0	0	0
Liver primary	0	0	0	0	129	0	0	0	0	0
Liver secondary	0	0	0	0	115	0	0	0	0	0
Bladder	99	0	0	0	0	0	0	0	0	0

Table 82: Results '1311' -35% demand

Type	*CZE*	*Anna*	*Elkerliek*	*MMC*	*MUMC*	*Maastro*	*Laurentius*	*SJG*	*VieCuri*	*Zuyderland*
Lung	0	0	0	0	0	0	0	0	0	196
Pancreas	0	0	0	0	73	0	0	0	0	0
Kidney	119	0	0	0	0	0	0	0	123	0
Cervical	59	0	0	0	0	0	0	0	0	0
Stomach	59	0	0	0	0	0	0	0	0	0
Oesopageal	66	0	0	0	0	0	0	0	0	0
Liver primary	0	0	0	0	149	0	0	0	0	0
Liver secondary	0	0	0	0	133	0	0	0	0	0
Bladder	114	0	0	0	0	0	0	0	0	0

Table 83: Results '1311' -25% demand

Type	*CZE*	*Anna*	*Elkerliek*	*MMC*	*MUMC*	*Maastro*	*Laurentius*	*SJG*	*VieCuri*	*Zuyderland*
Lung	0	0	0	123	0	0	0	0	0	100
Pancreas	0	0	0	0	82	0	0	0	0	0
Kidney	113	0	0	0	0	0	0	0	0	160
Cervical	51	0	0	0	0	0	0	0	0	0
Stomach	45	0	0	0	0	0	0	0	0	0
Oesopageal	74	0	0	0	0	0	0	0	0	0
Liver primary	0	0	0	0	168	0	0	0	0	0
Liver secondary	0	0	0	0	150	0	0	0	0	0
Bladder	130	0	0	0	0	0	0	0	0	0

Table 84: Results '1311' -15% demand

Type	CZE	Anna	Elkerliek	MMC	MUMC	Maastro	Laurentius	SJG	VieCuri	Zuyderland
Lung	100	0	0	0	101	0	0	0	0	100
Pancreas	50	0	0	0	61	0	0	0	0	0
Kidney	113	0	0	0	0	0	0	0	132	125
Cervical	0	0	0	0	0	0	70	0	0	0
Stomach	0	0	0	0	0	0	0	0	0	60
Oesopageal	51	0	0	0	0	0	0	0	0	50
Liver primary	0	0	0	100	128	0	0	0	0	0
Liver secondary	0	0	0	100	103	0	0	0	0	0
Bladder	175	0	0	0	0	0	0	0	0	0

Table 85: Results '1311' +15% demand

Type	CZE	Anna	Elkerliek	MMC	MUMC	Maastro	Laurentius	SJG	VieCuri	Zuyderland
Lung	0	0	0	0	100	0	127	0	0	100
Pancreas	53	0	0	0	67	0	0	0	0	0
Kidney	102	0	0	0	100	0	0	0	100	100
Cervical	76	0	0	0	0	0	0	0	0	0
Stomach	66	0	0	0	0	0	0	0	0	0
Oesopageal	52	0	0	0	0	0	0	0	0	57
Liver primary	0	0	0	112	135	0	0	0	0	0
Liver secondary	0	0	0	100	121	0	0	0	0	0
Bladder	191	0	0	0	0	0	0	0	0	0

Table 86: Results '1311' +25% demand

Type	CZE	Anna	Elkerliek	MMC	MUMC	Maastro	Laurentius	SJG	VieCuri	Zuyderland
Lung	107	0	0	0	100	0	0	0	0	146
Pancreas	80	0	0	0	51	0	0	0	0	0
Kidney	113	0	0	0	0	0	100	0	121	100
Cervical	82	0	0	0	0	0	0	0	0	0
Stomach	0	0	0	0	0	0	0	0	0	71
Oesopageal	68	0	0	0	0	0	0	0	0	50
Liver primary	0	0	0	141	126	0	0	0	0	0
Liver secondary	0	0	0	106	133	0	0	0	0	0
Bladder	106	0	0	0	100	0	0	0	0	0

Table 87: Results '1311' +35% demand