MASTER

Exploration of the link between the execution of a clinical process and its effectiveness using process mining techniques

Overduin, M.T.

Award date:
2013

Link to publication

Disclaimer
This document contains a student thesis (bachelor's or master's), as authored by a student at Eindhoven University of Technology. Student theses are made available in the TU/e repository upon obtaining the required degree. The grade received is not published on the document as presented in the repository. The required complexity or quality of research of student theses may vary by program, and the required minimum study period may vary in duration.

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

• Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
• You may not further distribute the material or use it for any profit-making activity or commercial gain
Exploration of the link between the execution of a clinical process and its effectiveness using process mining techniques

by

M.T. Overduin BSc

BSc Industrial Engineering and Management Science — TU/e 2011
Student identity number 0660315

in partial fulfilment of the requirements for the degree of

Master of Science
in Operations Management and Logistics

Supervisors:

Prof. Dr. Ir. H.A. Reijers, TU/e, Information Systems W&I
Dr. Ir. R.S. Mans, TU/e, Information Systems W&I
Dr. F.J.H.M. van den Biggelaar, MUMC+
Dr. R.M.M.A. Nuijts, MUMC+
TUE. School of Industrial Engineering.
Series Master Theses Operations Management and Logistics

Subject headings: business processes, health care, data analysis, improvement
Abstract
Healthcare organisations are continually searching for means to increase the efficiency and effectiveness of their clinical processes. Process mining can aid decision making concerning process design by giving insight into the current process execution and can hereby help in improving clinical care processes. No prior process mining case studies focused on the link between the execution of a (clinical) process and its effectiveness: a clear gap in process mining literature. This thesis explores this link in a case study on the cataract treatment process at the academical hospital of Maastricht. Four process mining analyses were conducted, each one comparing two patient groups. The groups were created based on chosen performance indicators that reflect process effectiveness from a patient perspective. Statistics was widely used in comparing the (time-) performance between the patient groups and evaluation sessions were held to be able to explain and ground the process mining results. This approach led to some interesting insights on the link and offered process improvement opportunities for the hospital. It was concluded that process mining techniques can certainly help in determining the link between process execution and process effectiveness and can hereby help in improving clinical care processes. Combining process mining with statistics and holding discussions (evaluations) with process owners were important parts of the research approach and can greatly help in drawing valid conclusions and in understanding the process mining results. The used research approach seems fruitful and should be applied in more case studies for validation purposes.
Management summary

Healthcare organisations are continually searching for means to increase the efficiency and effectiveness of their clinical processes. Increasing efficiency means achieving the same process outcomes with less means (doing things right). Increasing effectiveness means achieving better process outcomes (doing the right things). A proper balance between efficiency and effectiveness needs to be sought.

Process mining techniques make use of the fact that data about prior process executions is available in today’s information systems. Based on this information about what actually happened, the ordering and frequency of activities can be discovered (control-flow perspective), resource involvement can be discovered (organisational perspective) and the time-related performance of a process can be investigated (time perspective). Process mining hereby gives insight into the actual process execution. This can aid decision making concerning process design and process mining can hereby help in improving clinical care. No prior process mining case studies focused on the link between process execution and (clinical) process effectiveness: a clear gap in process mining literature. The research objective and question were

Research objective
To obtain exploratory insights into the use of process mining techniques for determining the link between the execution of a clinical treatment process and its effectiveness.

Main research question
Can process mining techniques help in determining the link between the execution of a clinical treatment process and its effectiveness?

Research sub-questions
1. Can process mining techniques help in determining the link between the ordering and frequency of activities of a clinical treatment process and its effectiveness?
2. Can process mining techniques help in determining the link between the resource involvement in a clinical treatment process and its effectiveness?
3. Can process mining techniques help in determining the link between the time-related performance of a clinical treatment process and its effectiveness?

A case study on the cataract treatment process at the academical hospital of Maastricht was conducted. The main research steps are given in the figure below.
Based on literature findings, a general clinical process effectiveness measurement framework was developed. Healthcare quality domains (De Koning & Hoeijmakers, 2007) lay the foundation. It was proposed that for each domain, performance indicators and accompanying goals could be established to make process effectiveness measurable: process executions can be classified as either successful or unsuccessful with respect to a performance indicator. Furthermore, it was also noted that effectiveness is actor-dependent. In this thesis the patient perspective was investigated. To apply the general clinical process effectiveness framework on the cataract treatment process, relevant indicators and goals that reflect the patient perspective in this treatment process were chosen in a selection process that emphasized rigour, relevance and took hospital data and research time restrictions into account. The resulting framework was

<table>
<thead>
<tr>
<th>Quality domain</th>
<th>Effectiveness Indicators</th>
<th>Effectiveness Goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clinical effectiveness</td>
<td>Volume of cataract treatments performed per surgeon</td>
<td>More than 250 surgeries per surgeon per year</td>
</tr>
<tr>
<td>Timeliness</td>
<td>1. Throughput time preoperative examination visit</td>
<td>Less than 80 minutes</td>
</tr>
<tr>
<td></td>
<td>2. Throughput time postoperative examination visit</td>
<td>Less than 40 minutes</td>
</tr>
<tr>
<td></td>
<td>3. Waiting time for surgery</td>
<td>Less than three weeks</td>
</tr>
<tr>
<td>Demand-orientation</td>
<td>Surgical continuity</td>
<td>Same medical specialist or junior doctor in training performs both cataract surgeries (one surgery per eye)</td>
</tr>
</tbody>
</table>

Subsequently, the required data was determined based on process mining literature and data was gathered from the hospital information system (SAP). Per performance indicator a separate process mining analysis was conducted. In each analysis two patient groups were created based on the effectiveness goal and the control-flow, organisational and time-perspectives were investigated. Each separate analysis was evaluated in separate sessions with a university and a hospital supervisor. The combined process mining results were evaluated in separate sessions with both university supervisors. The evaluations led to some additional research. Based on the combined results, the potential of process mining for investigating the link was determined.

Three process mining analyses focused on the high-level process: (1) the demand orientation analysis, (2) the high-level timeliness analysis and (3) the clinical effectiveness analysis. The low-level timeliness analysis zoomed in on the preoperative and final postoperative examination visits. The different process mining analyses led to interesting process insights and the different analyses complemented each other. Statistical tests were used to find proof for the found differences. The found differences could be explained by (a combination of) the surgery planning policy, the used triage categories, the patient volume and the surgical volume per surgeon. No differences in clinical effectiveness were found, only differences in timeliness and demand orientation effectiveness. The main insights gained were as follows
Demand orientation analysis insights

1. Surgical continuity (demand orientation effectiveness) interacts with timeliness: trade-off
2. Surgical continuity is influenced by the surgery planning policy and the triage policy

High-level timeliness analysis insights

1. The score on the Treeknorm (waiting time for surgery) most likely results from the high yearly inflow of patients (external factor) in combination with the emphasis on surgical continuity (internal factor)
2. The score can be possibly improved by putting less emphasis on surgical continuity

Low-level timeliness analysis insights

1. The low score on the benchmark times results from multiple causes
2. The high yearly inflow of patients (external factor) most likely contributes to the low score
3. Deviant patient visit status changes contribute to the low-score and are most likely done by optometrists. Lowering the amount of deviant patient visit status changes can improve the score on the benchmark throughput times
4. Further investigation into other causes is required
5. The fraction of patients that is too late for their appointment is high but in line with medical literature

Clinical effectiveness analysis insights

1. Patients that were treated by a high-volume surgeon had on average a shorter throughput time
2. The patient case mix of high-volume and low-volume surgeons differed

Concluding, process mining led to interesting insights on the link between process execution and process effectiveness. Process mining can thus certainly help in determining the link and can hereby help in finding process improvement opportunities. In the conducted analyses especially the organisational and time perspectives proved relevant. The control-flow perspective was only to some extent useful. Process mining is however only one tool out of the toolbox for determining the link. By combining process mining with other tools, such as statistics and discussions with process owners, a rich and valid understanding of the link can be gained for the investigated process. This approach was used in this thesis project.

Based on this research, several process improvements were recommended. From a scientific point of view, it would be valuable to apply the used methodology in more cases studies The applied methodology was fruitful in this exploratory study, but more scientific evidence of its effectiveness is needed. Furthermore, it would be valuable to investigate the data perspective of process mining, the link with clinical effectiveness and to look into integrating statistics within process mining. The latter would greatly ease drawing valid conclusions.
Acknowledgements

In front of you is the result of my graduation project for the master program Operations, Management and Logistics at the Eindhoven university of Technology. I conducted this research at and in cooperation with the academic hospital of Maastricht (MUMC+).

I would like to thank the people that helped and supported me during this research. First, I would like to thank Hajo Reijers, for his enthusiastic response to my proposal of the thesis topic and his useful input and feedback during our Friday-afternoon meetings. Ronny Mans, for all the travels he made to Maastricht to help with obtaining the data and the time he found for all the discussions on process mining, the case study outcomes and this research in general.

At the academical hospital of Maastricht I would like to thank Frank van den Biggelaar for his clear explanation of the relevant policies at the department and his feedback on the case study outcomes. Often I could just walk in to have a chat about research findings, this was much appreciated. Rudy Nuijts, for the good laugh we had during meetings and his initial criticism and scepticism on process mining. This kept me sharp and contributed to the foundations of the case study results. Rob Vanwersch, for making the initial contact with the hospital and his useful feedback and suggestions.

I also would like to thank my friends for their interest in my research and the sought after diversion after hard work. This was much appreciated.

The last words are for my girlfriend Hanna and my family. Their continuous support, especially during an unexpected time of illness, interest and trust in me motivated me to keep going, laughing, put things into perspective and to make the most of it.

Mark Overduin
Eindhoven, September 2013
Contents

Abstract .......................................................................................................................... iii
Management summary ...................................................................................................... iv
Acknowledgements ......................................................................................................... vii
Contents ........................................................................................................................... viii
List of Figures ..................................................................................................................... ix
List of Tables ....................................................................................................................... ix
1. Introduction .................................................................................................................... 1
   1.1. Research objective and questions ........................................................................... 2
   1.2. Document structure ................................................................................................. 2
2. Preliminaries .................................................................................................................. 3
   2.1. Organisational Management domain ...................................................................... 3
   2.2. Information Technology domain ............................................................................ 6
   2.3. Health domain ....................................................................................................... 8
3. Methodology .................................................................................................................. 10
   3.1. Research process methodology .............................................................................. 10
   3.2. Developing the general clinical process effectiveness measurement framework ...... 11
   3.3. Developing the MUMC+ cataract treatment process effectiveness framework ....... 12
   3.4. Data requirements ................................................................................................. 17
   3.5. Data collection ....................................................................................................... 17
   3.6. Research scope restrictions ................................................................................... 19
4. Process mining analyses ............................................................................................. 20
   4.1. Demand orientation analysis ................................................................................. 20
   4.2. Timeliness analysis ............................................................................................... 27
   4.3. Clinical effectiveness analysis .............................................................................. 38
5. Evaluation and additional research ............................................................................ 43
   5.1. High-level process ................................................................................................. 43
   5.2. Low-level process (examination visits) ................................................................. 44
   5.3. Additional research ............................................................................................... 45
6. Conclusion ..................................................................................................................... 47
7. Discussion and recommendations ............................................................................... 49
References ....................................................................................................................... 51
Appendices ..................................................................................................................... 54
Appendix A: General planning surgeries and postoperative examinations ................... 54
Appendix B: Catquest-9SF questionnaire (in Dutch) ....................................................... 55
Appendix C: Pre-analysis questionnaire (in Dutch) ......................................................... 58
Appendix D: Descriptive statistics pre-analysis ............................................................... 62
Appendix E: Demand orientation analysis selection steps in Microsoft Access ............... 63
Appendix F: Demand orientation analysis Microsoft Access queries .............................. 64
Appendix G: High-level timeliness analysis selection steps in Microsoft Access ............. 68
Appendix H: High-level timeliness analysis Microsoft Access queries ............................ 69
Appendix I: Low-level timeliness analysis selection steps in Microsoft Access ............... 73
Appendix J: Low-level timeliness analysis Microsoft Access queries .............................. 74
Appendix K: Clinical effectiveness analysis selection steps in Microsoft Access ............. 76
Appendix L: Clinical effectiveness analysis Microsoft Access queries ............................ 77
Appendix M: Boxplot outlier removal throughput time clinical effectiveness analysis ....... 80
Appendix N: Graphical overview time to surgery for created patient groups .................. 81

List of Figures
Figure 1: Scientific position thesis ............................................................................. 3
Figure 2: Overview model of process mining (Van der Aalst, 2011) .......................... 6
Figure 3: Research process methodology (high-level) ................................................. 10
Figure 4: Perform process mining (low-level) ............................................................. 10
Figure 5: High-level process model cataract centre MUMC+ ..................................... 12
Figure 6: UML diagram registration of occurred events ............................................. 18
Figure 7: Structure analysis chapter .......................................................................... 20
Figure 8: Preliminary process model demand orientation analysis ............................ 22
Figure 9: Control-flow (surgical continuity) .............................................................. 23
Figure 10: Control-flow (surgical discontinuity) ......................................................... 23
Figure 11: Process milestones cataract treatment process ........................................... 24
Figure 12: Main findings demand orientation analysis .............................................. 26
Figure 13: Preliminary process model high-level timeliness analysis ......................... 28
Figure 14: Control-flow group 2 (first surgery > 21 days) ................................ .......... 29
Figure 15: Control-flow group 1 (first surgery <= 21 days) ......................................... 29
Figure 16: Histogram time between preoperative examination and the first surgery .. 30
Figure 17: Main findings high-level timeliness analysis ............................................. 31
Figure 18: Preliminary process model pre-operative examination ............................. 32
Figure 19: Main process steps examination visit ....................................................... 33
Figure 20: Preliminary process model final postoperative examination ...................... 33
Figure 21: Preoperative examination (group 2) .......................................................... 35
Figure 22: Preoperative examination (group 1) .......................................................... 35
Figure 23: Final postoperative examination (group 2) ............................................... 35
Figure 24: Final postoperative examination visit (group 1) ......................................... 35
Figure 25: Histogram throughput time preoperative examination visit ..................... 36
Figure 26: Histogram throughput time final postoperative examination visit ............. 36
Figure 27: Preliminary process model clinical effectiveness analysis ....................... 39
Figure 28: Distribution of surgeries among medical specialists and junior doctors ....... 40

List of Tables
Table 1: Healthcare quality domains. Translated from: De Koning & Hoeijmakers (2007) .... 5
Table 2: General clinical process effectiveness measurement framework .................. 11
Table 3: Preliminary performance indicators ............................................................. 14
Table 4: MUMC+ cataract treatment process effectiveness measurement framework .. 17
Table 5: Organisational function of the surgeon (per group and over-all) ................. 24
Table 6: Time analysis results (demand orientation analysis) ..................................... 25
Table 7: Frequency of occurrence of potentially interesting services ....................... 40
Table 8: Time analysis findings (clinical effectiveness analysis) ............................... 41
Table 9: Created patient groups with time to surgery averages (additional research part 1).... 45
Table 10: Created patient groups with time to surgery averages (additional research part 2).... 46
1. Introduction
Healthcare organisations face very complex challenges these days. The demand for care is rising in Dutch society (Dutch central bureau of statistics (CBS), 2011, p. 16) and patients are increasingly more demanding when it comes to the clinical outcomes of care and their care experience. At the same time, the government is pursuing budget cuts in the domain (Dutch ministry of Health, Welfare and Sports, 2012, p. 130) and the medical insurance companies use their buying power to get affordable prices (Dutch ministry of Health, Welfare and Sports, 2012, p. 14). The ageing population, consumerism, and the continuing economic recession are some underlying factors contributing to the very complex challenges at hand.

In order to cope with these challenges, healthcare organisations are continuously searching for means to improve the efficiency and effectiveness of their organisation structure and their clinical treatment processes. Altering clinical care processes can enhance the efficiency – achieving the same process outcomes with less means (doing things right) and/or can improve the effectiveness. Effectiveness is in the Cambridge dictionary simply defined as being successful. In the context of processes this means achieving the desired outcomes of a process (doing the right things). Process efficiency and process effectiveness are defined in more detail in chapter 2 (Preliminaries). A proper balance between efficiency and effectiveness needs to be sought to be able to offer affordable and timely services that meet the high quality standards demanded by patients, the medical insurance companies and society at large.

Process mining techniques make use of the fact that data about prior process executions is available in today’s information systems. Based on this information about what actually happened, the ordering and frequency of activities can be discovered (control-flow perspective), resource involvement can be discovered (organisational perspective) and the time-related performance of a process can be investigated (time perspective) (IEEE Taskforce on Process Mining, 2012, p. 5). These perspectives are outlined in more detail in chapter 2 (Preliminaries). Process mining hereby gives insight into the actual process execution. This can aid decision making (by managers) concerning process design and process mining can hereby help in improving clinical care processes by enhancing the process efficiency and/or the process effectiveness.

In the preceding literature study (Overduin, 2013) it was found that the link between process execution and (clinical) process efficiency has been investigated using process mining in some prior studies in healthcare and industry. Little prior research was done however on the link between process execution and (clinical) process effectiveness using process mining techniques. Peleg et al. (2008) is the only found exception. Based on the challenges faced by healthcare organisations and the identified gap in current process mining research, the main problem that drove this thesis project was formulated as follows

<table>
<thead>
<tr>
<th>Main problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>It is unknown if and how process mining techniques can help in determining the link between the execution of a clinical treatment process and its effectiveness.</td>
</tr>
</tbody>
</table>
1.1. Research objective and questions

Based on this main problem, the research objective was formulated as follows

**Research objective**

To obtain exploratory insights into the use of process mining techniques for determining the link between the execution of a clinical treatment process and its effectiveness.

This objective covers the fact that this thesis project was of an exploratory nature and that the main goal was to gain insight into the usefulness of using process mining techniques for determining the link. Insights from the control-flow, organisational and time perspective were investigated. The time perspective was particularly interesting since the current challenges for healthcare organisations demand attention to both the efficiency and the effectiveness of care processes. To achieve this objective, a case study was performed at the ophthalmology department of the academic medical centre of Maastricht (MUMC+). The cataract treatment process was investigated. This is outlined in more detail in section 3 (Methodology). The following main research question was developed based on the research objective

**Main research question**

Can process mining techniques help in determining the link between the execution of a clinical treatment process and its effectiveness?

There are multiple perspectives one can take when using process mining. Three of these perspectives— the control-flow, organisational and time perspective, were investigated. This gave a natural division for creating sub-questions. The following research sub-questions were developed

**Research sub-questions**

1. Can process mining techniques help in determining the link between the ordering and frequency of activities of a clinical treatment process and its effectiveness?
2. Can process mining techniques help in determining the link between the resource involvement in a clinical treatment process and its effectiveness?
3. Can process mining techniques help in determining the link between the time-related performance of a clinical treatment process and its effectiveness?

1.2. Document structure

The rest of this document is structured as follows. Chapter 2 outlines the project’s preliminaries. Chapter 3 outlines the research methodology. Chapter 4 contains the performed process mining analyses. In chapter 5 the combined process mining results are evaluated. Chapter 6 contains the research conclusions. Chapter 7 finalizes this thesis by discussing this research, its outcomes and by making recommendations for practice and further academic research.
2. Preliminaries

This chapter covers the academic preliminaries of this thesis project. This thesis project is on the interface of the health, information technology and organisational management academic research domains (see Figure 1). Section 2.1 covers the organisational management domain. Section 2.2 covers the information technology domain. Section 2.3 covers the health domain.

2.1. Organisational Management domain

In this section the relevant preliminaries of the organisational management domain are discussed. Since this thesis project was performed in the healthcare domain, this section is tailored towards management in the healthcare domain. In subsection 2.2.1 business processes are briefly discussed. Subsection 2.2.2 covers the concept ‘process efficiency’. In subsection 2.2.3 the concept ‘process effectiveness’ is outlined. Subsection 2.2.4 finalizes this section by outlining the concept ‘quality of care’.

2.1.1. Business processes

Healthcare processes, which are medical business processes, can be subdivided into clinical treatment processes and generic organisational processes (Lenz and Reichert, 2007). Generic organisational processes support the clinical treatment processes. Patient scheduling is an example of a generic organisational process (Rebuge and Ferreira, 2012). Looking at (business) processes is an important concept in achieving effective collaboration between different organisational resources (Weske, 2007). Weske (2007) defines a business process as follows

“A business process consists of a set of activities that are performed in coordination in an organisational and technical environment. These activities jointly realise a business goal. Each business process is enacted by a single organisation, but it may interact with business processes performed by other organisations.”

Weske thus identifies that coordination is required in a business process, since activities jointly realise a business goal (outcome). Furthermore, he limits his definition by focusing on processes that are enacted by a single organisation, hereby excluding cross-organisational processes.
In business processes there is often a clear case (or a set of cases) on which the different activities are performed. In generic organisational processes this might be for example an order. In clinical treatment processes the patient is often the case. Execution is defined in the Cambridge dictionary as the act of doing or performing something. Process execution can thus be defined as the act of performing a process.

2.1.2. Process efficiency

One can distinguish between two types of process efficiency: technical efficiency and allocative efficiency (Hollingsworth, 2008). A process is technically efficient if the maximum amount of output is produced from a given amount of input or a given output is produced with minimum input quantities. Allocative efficiency is achieved when the input mix minimizes cost, given input prices or when the output mix is that which maximizes revenue, given output prices. Efficiency is a multi-dimensional concept: a process can be efficient from a time-perspective, but simultaneously inefficient from a cost-perspective and from a quality-perspective. In this thesis the time-dimension of technical efficiency was taken into account while investigating process effectiveness.

To measure efficiency in the healthcare domain often ratios, expressed in percentages, are used (Hussey et al., 2009). Ratios have the advantage that they are relatively easy to calculate and interpret. They are, however, only single numeric values. One has to be careful not to misinterpret these measures. Ratios are a subset of performance indicators (Berg et al., 2005). Performance indicators are single numeric values as well, but not necessarily percentages (e.g. the average waiting time in a process).

2.1.3. Process effectiveness

Efficiency focuses on the process of transforming inputs into outputs and outcomes. Effectiveness on the other hand purely focuses on the outputs/outcomes of this conversion process. Process effectiveness is all about doing the right things. Fishman et al. (2004) mention that most medical effectiveness research until now used health services variables as output measures instead of health outcome measures. This is congruent with the findings of (Hussey et al., 2009). A distinction should be drawn between the clinical quality of care and the quality of the care experience. Clinical processes can be clinically effective but simultaneously ineffective from a patient point of view if the care experience is lacking (e.g. not being treated in a timely manner according to a patient’s standards). In this thesis project, effectiveness was simply defined as being successful. Effectiveness is seen as a multi-dimensional construct, just as efficiency is.

Furthermore, for a clinical process there are different actors that have different notions of what success pertains to a certain process. Based on these different effectiveness dimensions and actor interests, performance indicators (as introduced in subsection 2.1.2) can be formulated to operationalize the concept of process effectiveness. Indicators make process effectiveness measurable. For indicators, measurable goals can be developed. Goals can be seen as cut-off points for indicators that determine if a process was executed either successfully or unsuccessfully.
2.1.4. Quality of care

In the healthcare domain, clinical process effectiveness is closely related to the concept of quality of care. The Institute of Medicine (IOM) views quality of care as a multi-dimensional concept and distinguishes four domains: (1) effectiveness, (2) safety, (3) timeliness and (4) demand-orientation (IOM, 2001). De Koning & Hoeijmakers (2007) extended this framework with two domains, accessibility and efficiency. In Table 1 these healthcare quality domains are given and defined.

<table>
<thead>
<tr>
<th>Quality domain</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effectiveness</td>
<td>The level of achieving formulated goals in practice</td>
</tr>
<tr>
<td>Timeliness</td>
<td>Offering (preventive) care at the right moment and prevent unnecessary waiting times after a positive screening score</td>
</tr>
<tr>
<td>Efficiency</td>
<td>Care that prevents waste</td>
</tr>
<tr>
<td>Safety</td>
<td>Preventing for damage during medical interventions that are aimed at improving health</td>
</tr>
<tr>
<td>Accessibility</td>
<td>Accessibility to care (facilities) and interventions is not restricted by characteristics such as gender or ethnicity</td>
</tr>
<tr>
<td>Demand-orientation</td>
<td>Respecting the preferences, needs and wants of patients and acting upon those</td>
</tr>
</tbody>
</table>

The American Institute of Medicine (IOM) uses the following definition for quality of care:

“Quality of care is the degree to which health services for individuals and populations increase the likelihood of desired health outcomes and are consistent with current professional knowledge.” (IOM, 2001).

If one defines effectiveness simply as being successful and if one acknowledges that effectiveness is a multi-dimensional construct (e.g. the clinical outcome and the quality of the care experience both matter) and that effectiveness is actor-dependent, then the definition of quality of care of the IOM should be formulated broader. Quality of care should not only be seen as the contribution that health services, a set of clinical and organisational processes, can deliver in achieving clinical effectiveness (‘increase the likelihood of desired health outcomes’). Rather it should be seen as the contribution that health services can make in achieving the goals of the main actors in the healthcare processes, among others the patient and the healthcare institution itself. In this thesis, a patient perspective was used and patient’s interests (goals) were investigated. Indicators and accompanying goals that operationalize effectiveness should be included within each quality domain (e.g. efficiency domain goals). The IOM sees effectiveness as a distinct domain, but this domain should be narrowed down to clinical effectiveness, since this is not covered by the other quality domains. Accessibility is a process external quality domain: it is not measurable within a process. The other domains are internal quality domains.
2.2. Information Technology domain

In this section relevant parts of the Information Technology domain are set forth. Subsection 2.2.1 describes the fundamentals of process mining. In subsection 2.2.2 healthcare domain specific challenges for applying process mining are discussed. Lastly, section 2.2.3 discusses the preceding process mining research on process effectiveness.

2.2.1. Process mining fundamentals

Process mining is concerned with the evaluation of the process execution. Process mining is an important bridge between data mining and business process modelling and analysis (Van der Aalst, 2011). Van der Aalst describes the main idea of process mining as follows

“To discover, monitor and improve real processes by extracting knowledge from event logs readily available in today’s systems.” (Van der Aalst, 2011)

Event logs provide detailed information about process activities (events) that have been executed previously and hereby serve as the starting point and the data-input for process mining techniques. To clearly explain the concept of process mining further, it is a good idea to have a look at the overview model that Van der Aalst offers, see Figure 2. The cloud on the top-left represents the real world: the actual business processes in organisations and the people, machines and other resources that are involved in the business processes. These business processes are often supported and/or controlled by (software) systems, which is visualized on the top-right. Activities that have been executed on a case have accompanying records that are stored in databases. Per case a trace of events (activities) is recorded (Van der Aalst, 2011).

![Figure 2: Overview model of process mining (Van der Aalst, 2011)](image)

Extra information that can be recorded consists of for example timestamps (the time that an event occurred), the resource executing or initiating the activity (e.g. a dentist) and other data elements (e.g. the occurrence of a complication). All records registered in the event logs in database systems (bottom-right of Figure 2) form the input for process mining techniques, as visualized at the bottom of Figure 2.
Van der Aalst distinguishes different perspectives that one can use while performing process mining. Perspectives can be seen as the glasses through which you look when performing process mining. Among these are (1) **the control-flow perspective**, (2) **the organisational perspective** and (3) **the time perspective** (Van der Aalst, 2011). Firstly, the control-flow perspective focuses on the ordering and frequency of activities: e.g. all possible paths that patients can take through a process. Secondly, the organisational perspective focuses on all information contained in the event logs about the resources that are involved in the process execution. For example, who hands over work to whom. Lastly, the time perspective focuses on the timing of events. One could think here of discovering performance bottlenecks (Van der Aalst, 2011). The different perspectives can complement each other. In this thesis project these three perspectives were explored.

### 2.2.2. Healthcare domain-specific challenges for applying process mining

Healthcare is characterized by highly complex and extremely flexible care processes where many disciplines are involved (Mans, 2008a), (Rebuge and Ferreira, 2012), (Gattnar et al., 2011). These disciplines often work in isolation and IT systems are often scattered and independently developed/customized (Mans, 2008), (Mans, 2008a), (Lenz et al., 2012). This poses challenges to data gathering from IT systems and to applying process mining techniques in the domain.

Mans et al. (2013) investigated the **data gathering challenges** that have to be faced when using process mining in the healthcare domain. The process mining data spectrum is based on two dimensions: (1) **level of abstraction** and (2) **accuracy of timestamp**. Mans et al. (2013) distinguish four classes of systems: (1) administrative systems, (2) clinical support systems, (3) healthcare logistics systems and (4) medical devices. Typically only data from administrative systems is currently used for process mining studies. As a result frequently posed (managerial) questions can often only be answered ‘up to a certain level’. The main data problems currently have to do with (1) the granularity of the timestamps and (2) the correctness of the timestamp. Augmenting the dataset with information from other Hospital Information Systems (HISs) next to administrative systems can enhance process mining results (Mans et al., 2013).

### 2.2.3. Preceding process mining research focusing on process effectiveness

Peleg et al. (2008) motivate the **extension of process mining** in their position paper ‘in order to capture not only deviations from the process model, but also the outcomes associated with them’ (Peleg et al., 2008). These could be **process outcomes** such as ‘the patient is improving’ or ‘the patient is deteriorating’. Hereby the authors place specific focus on the clinical effectiveness of process performance. The authors demonstrated their approach using an example based on the treatment of ear infections (acute otitis media, AOM). They did not carry out a case study however to test their extension proposal. In this thesis the clear **literature gap** with respect to the link between process execution and process outcomes (effectiveness) was investigated.
2.3. Health domain

In this section the relevant preliminaries of the health domain are discussed. Since the case study in this thesis focused on the cataract treatment process, the disease cataract and its treatment are central. Subsection 2.3.1 focuses on the disease cataract. In subsection 2.3.2 the treatment of cataract is outlined. In this thesis project the patient perspective and the patients interests (goals) were investigated (see also section 2.1.4), therefore patient care priorities are discussed in subsection 2.3.3.

2.3.1. Cataract

Cataract is a light-scattering disorder of the crystalline lens that is an important cause of visual impairment worldwide (Shiels et al., 2010). Cataract is typically acquired with age (older than 50 years) as a multi-factorial disorder ‘involving complex interactions between genetic and environmental risks’ (McCarty & Taylor, 2001). Often both eyes are affected and both need to be treated in separate surgeries. In some cases, cataract may be inherited as a classic Mendelian disorder (approximately 1/10,000 births) (Shiels et al., 2010).

2.3.2. Cataract treatment

Cataract is treated by performing cataract surgery. At a cataract surgery the original eye lens core is removed (Olson et al., 2003). Up to the 1980s, the prevailing procedure was intracapsular cataract extraction (ICCE) (Olson et al., 2003). At ICCE, the whole lens including the lens capsule was removed through a 180 degrees incision in the cornea. Placing a new intra ocular lens (IOL) was impossible, since there was no remaining structure to attach the new lens to. In the 1980s there was a transition to extracapsular cataract extraction (ECCE) combined with placing a new IOL (Olson et al., 2003). Using ECCE, only the lens core was removed. This method was prevailing until the end of the 1990s.

Phacoemulsification is an innovative way to remove cataracts through a much smaller incision (Olson et al., 2003). At phacoemulsification a small phaco probe is entered into the original lens and using ultrasound the lens core is emulsified (Olson et al., 2003) and removed through the phaco probe. When foldable lenses were subsequently evolved, physicians could take advantage of the incision size advantage of phacoemulsification. Incision sizes went down to as small as 1.5 mm (Olson et al., 2003). Furthermore, cataract treatment went from an inpatient procedure with a hospital stay up to 1 week to an outpatient treatment with little limitation to a patient’s postoperative activities. These days, using phacoemulsification in combination with a foldable lens is the prevailing treatment method for cataract.

In broad terms, the desired clinical outcome of a cataract treatment is improved vision. Two important and commonly used vision measures are (1) the refractive accuracy and (2) the visual acuity (Hahn et al., 2011). The refractive accuracy measures whether a person is short-sighted or far-sighted. This is measured in dioptres (D). Visual acuity is the acuteness or clearness of vision. It is measured in an eye exam using Snellen charts. The visual acuity is not only dependent on the sharpness of the retinal focus within the eye, but also on the sensitivity of the interpretative faculty of the brain (Cline et al., 1997). Next to the refractive accuracy and visual acuity, other vision characteristics, such as the presence of
glare, are also important in determining the clinical outcome of a cataract treatment. There are no uniform clinical outcome benchmarks for cataract treatments defined in medical literature. Complicating factors in formulating uniform benchmarks are patient characteristics such as ocular comorbidities, technical differences, implants and examination conditions. These all may have an influence on the surgery outcome and the outcome can thus only partially be contributed to the quality of the medical performance itself (Hahn et al., 2011). In one study, (Hahn et al., 2011), valid benchmarks for the refractive accuracy and the visual acuity were derived for a patient group. These are however only valid for the specific patient group researched. Hahn et al. (2011) mention “deriving benchmarks for a general patient population (including all possible confounding factors) will remain a theoretical approach of questionable validity and limited relevance for everyday practice”.

Alternatively, one can use process measures which can serve as proxies for the clinical outcome (Zichtbare Zorg, 2013). An example of a process measure is the volume of cataract surgeries. Research shows for an increasing number of disorders that the quality is better if the care team has more experience (Begg, 1998) (Birkmeyer, 2001) (Dudley, 2004) (Luft, 1979). Canadian research shows some evidence for the existence of a relation between the volume per surgeon and the quality of care at cataract surgeries (Bell, 2007). It was found that surgeons who performed 50-250 cataract surgeries per year had an adverse event rate of 0.4 per cent. Surgeons that performed 251-500, 501-1000 and >1000 surgeries per year had an adverse event rate of respectively 0.2, 0.2 and 0.1 per cent. Note that process measures are not case-based: they do not tell for each patient what the clinical outcome was. They can, however, give an indication of expected differences in the clinical outcome distribution (e.g. complications) between patient groups. Another alternative is to measure the perceived clinical outcome of a cataract treatment. Patient reported outcome measures (PROMs) can be used for this end. Several cataract specific questionnaires exist—amongst others the Catquest-9SF and Visual Function 14 (VF-14) questionnaire (Lundström & Pesudovs, 2009). The Catquest-9SF questionnaire was used in the discussion of this research to determine the potential of structurally capturing this information for process mining purposes in the future. This questionnaire was chosen since it is a valid and short-form (9 questions) visual disability instrument.

2.3.3. Patient priorities

Here the general priorities of patients concerning their healthcare are outlined. These are used in the construction of the process effectiveness measurement framework (Chapter 3—Methodology). Detsky (2011) mentions the following general priorities that patients place on healthcare: (1) restoring health when ill (reactive medicine), (2) timely access to health services, also discussed by (Maa, 2011), (3) to be treated with kindness, empathy and respect for their privacy, (4) to be offered hope and certainty, also discussed by (Srivastava, 2010), (5) continuity of care (same person or care team in each episode of a similar illness) and involvement in decision making (Fowler, Jr., 2011), (6) a private room (for inpatient treatments), also discussed by (Detsky & Etchells, 2008), (7) No out-of-the-pocket costs (insurance cover), (8) information about clinician qualifications (the best medicine) and lastly (9) medication and surgical treatments are preferred above treatments that involve behavioural changes: patients prefer little effort from their side.
3. Methodology

The methodology used to answer the research question and to achieve the research objective is outlined in this chapter. First, the research process methodology is outlined (section 3.1). Second, the development of a general clinical process effectiveness measurement framework is outlined (section 3.2), followed by sections on the development of the MUMC+ cataract treatment process effectiveness measurement framework (section 3.3), data requirements (3.4), data collection (3.5) and lastly the research scope restrictions (section 3.6).

3.1. Research process methodology

Here the main research steps are described (Figure 3). Based on literature a general clinical process effectiveness measurement framework was developed. To use this framework on the cataract treatment process at MUMC+, case-study specific performance indicators and goals were determined in a selection process, in which a pre-analysis was included. The pre-analysis consisted of a patient questionnaire, combined with discussions and observations. The resulting MUMC+ cataract treatment process effectiveness measurement framework determined the required data-input for the process mining investigation. Subsequently, the data was gathered and the process mining investigation was carried out. The process mining investigation consisted of several separate analyses, one analysis per performance indicator. The combined process mining results were evaluated in separate sessions with both university supervisors. The main research steps are given in Figure 3. The evaluation led to some additional research in this thesis project, but this is not necessarily the case in similar future studies, hence the (XOR-)split. Lastly, the potential of process mining for determining the link between process execution and process effectiveness was determined based on the evaluation and the additional research.

Performing process mining forms an important part of the research process. The used process mining methodology is depicted in Figure 4.
The main inspiration for the used process mining methodology came from Rebuge and Ferreira (2012), who developed a process mining methodology which they used successfully in the healthcare domain. In the used process mining methodology log preparation and log inspection were carried out, followed by creating groups of patients based on an effectiveness indicator (performance indicator), using an effectiveness goal as cut-off point. The MUMC+ cataract treatment process effectiveness measurement framework was used for this purpose. If necessary, the framework was adapted after log inspection (additional insight). After group creation, the control-flow, organisational and time analysis were conducted. The results were integrated and evaluated in separate sessions with a university and a MUMC+ supervisor. These evaluations led to some additional research, hence the feed-back loop. This process mining methodology was carried out for each researched process effectiveness performance indicator.

3.2. Developing the general clinical process effectiveness measurement framework

In chapter 2 (Preliminaries) healthcare quality domains were introduced and it was mentioned that process effectiveness can be operationalized for a clinical treatment process by using measurable performance indicators (introduced in subsection 2.1.2) and by setting goals for these indicators, that serve as a cut-off point to determine whether a process execution is either successful or unsuccessful (introduced in subsection 2.1.3). This formed the basis for creating a general clinical process effectiveness measurement framework.

In subsection 2.1.4 it was mentioned that the following internal quality domains are distinguished in the healthcare domain: effectiveness, timeliness, efficiency, safety and demand-orientation. Using the reasoning that process effectiveness can be measured within (and for) each domain, effectiveness should not be put forth as a separate quality domain. However, clinical effectiveness does not fit in the other quality domains. Therefore, it is proposed in this thesis to replace the effectiveness quality domain with a clinical effectiveness quality domain. Based on these five process internal quality domains a general clinical process effectiveness measurement framework was constructed, see Table 2. Examples of possible indicators and goals are given in Table 2. In subsection 3.3 the indicators and goals used in this thesis are given.

Table 2: General clinical process effectiveness measurement framework

<table>
<thead>
<tr>
<th>Quality domain</th>
<th>Effectiveness Indicators</th>
<th>Effectiveness Goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clinical effectiveness</td>
<td>E.g. volume of cataract surgeries</td>
<td>E.g. more than 250 surgeries per surgeon (adverse event rate of 0.2 per cent)</td>
</tr>
<tr>
<td>Timeliness</td>
<td>E.g. time between diagnosis and treatment</td>
<td>E.g. time between diagnosis and treatment is less than 3 weeks</td>
</tr>
<tr>
<td>Efficiency</td>
<td>E.g. cost of treatment</td>
<td>E.g. less than 5000 euro per treatment</td>
</tr>
<tr>
<td>Safety</td>
<td>E.g. complication X</td>
<td>E.g. complication X never occurs</td>
</tr>
<tr>
<td>Demand-orientation</td>
<td>E.g. same doctor involved in all surgeries in a clinical treatment process</td>
<td>E.g. in more than 90% of all process executions the same doctor is involved in all surgeries</td>
</tr>
</tbody>
</table>
3.3. Developing the MUMC+ cataract treatment process effectiveness framework

To apply the general clinical process effectiveness framework on the cataract treatment process, relevant indicators and goals that reflect the patient’s interests in this treatment process were chosen. This section starts with a brief delineation of the cataract treatment process at MUMC+ (subsection 3.3.1). Hereafter the selection process of performance indicators (subsection 3.3.2) and the pre-analysis (subsection 3.3.3) are covered, followed by the introduction of the MUMC+ cataract treatment process effectiveness measurement framework (subsection 3.3.4).

3.3.1. Cataract treatment process at MUMC+

The cataract treatment process at MUMC+ was used as a case study in this thesis project. This process was chosen since this process is clinically straightforward (hereby limiting the complexity of the analyses), well academically researched due to its high patient volume in general (hereby aiding in the choice for performance indicators and goals), well documented at MUMC+ and the high patient volume makes statistical analysis of process mining results possible. A reflection on the case study choice is given in chapter 7 (Discussion and recommendations). At MUMC+ cataracts are treated at the cataract centre of the academic clinic for ophthalmology. The standard procedure is to use phacoemulsification in combination with a foldable lens (the standard these days). The required pre-operative eye tests are scheduled on one day together with a consultation with a junior doctor which is supervised by a medical specialist. The tests and consultation together form the pre-operative examination. On this day appointments are made for both surgeries as well as the post-operative examination visits. The surgery itself is an outpatient procedure. The day after the treatment there is either a consultation by phone, if a medical specialist carried out the surgery, or a physical examination, if a junior doctor in carried out the procedure. After a week there is a physical examination. The results from the first cataract treatment are taken into account when performing the second surgery. The MUMC+ policy is to plan the second surgery at least 14 days after the first surgery. If the second eye is not treated, there is a final postoperative examination five weeks after the first surgery. If the second eye is treated, there is a physical examination (surgery by junior doctor) or consult by phone (surgery by medical specialist) one day after the surgery and physical examinations one and five weeks after the procedure. A process model is given in Figure 5.

![Process Diagram](image)

**Figure 5:** High-level process model cataract centre MUMC+
3.3.2. Performance indicator and goal selection process

The literature on patient priorities lay at the basis of the selection process. The following four steps were used in the selection process:

1. Choose patient priorities that are theoretically relevant for the cataract treatment process, represent the healthcare quality domains, are quantitatively measurable, could logically be applied based on information captured by MUMC+ and could easily be used in process mining software for creating patient groups.
2. Choose (preliminary) performance indicators that can operationalize these patient priorities.
3. Check the practical relevance of the chosen patient priorities and performance indicators.

First, patient priorities were chosen (from the list of subsection 2.3.3) that meet the selection criteria of step 1. The patient priorities *restoring health when ill*, *timeliness* and *continuity* are directly relevant for the cataract treatment process, are quantitatively measurable using process mining techniques (see also section 3.4) and have a direct relationship with respectively the quality domains clinical effectiveness, timeliness and demand-orientation. Furthermore, they could be logically applied based on information captured by MUMC+ and could possibly be easily used within process mining software.

*Kindness, choice, coordination* and *certainty* were considered possibly relevant for the cataract treatment process. These constructs were however impossible to investigate using the current data captured in the MUMC+’ hospital information systems (HISs) (see also section 3.4).

The patient priority *hope* was considered irrelevant for the cataract treatment process since cataract is not a fatal disease and has a very high success rate (inferred from the very low adverse event rates, see section 2.3.2). The patient priority *private room* was considered irrelevant since cataract treatment is (if all goes well) an outpatient procedure. The patient priority *information about clinician qualifications* is not measurable using process mining techniques since it is not directly coupled to the actual process execution, it rather has to do with the physician choice before the process execution. The patient priority *out-of-the-pocket costs* was considered irrelevant for the cataract treatment process, since the only significant variation source in out-of-the-pocket costs is the lens choice that the patients make. It is dependent on the patient’s insurance cover whether these lens costs are either in-the-pocket or out-of-the-pocket. Lastly, the priority *medication and treatment* was considered irrelevant, since cataract is always a surgical procedure and little (or no) behavioural changes are required.

Second, it was determined how these patient priorities could be operationalized using *performance indicators*. To measure *restoring health when ill* it was preferred to use the results of eye tests performed at both the preoperative and final postoperative examination. This would be a direct clinical effectiveness measure that is also case-based. These test results
were however not directly available in the hospital’s central information system, rather the result-forms were entered as photographic scans. Furthermore, it was impossible to take all the ocular comorbidities (possibly treated at another healthcare institution), technical differences, implants and examination conditions into account using the information in the central hospital information system. This is needed however to provide valid benchmarks (see also subsection 2.3.2). Alternatively, the found relationship between the volume of cataract surgeries per surgeon and the adverse event rate (subsection 2.3.2, a process measure) was used as a basis for creating patient groups. The indicator volume of cataract surgeries per surgeon could easily be implemented using the existing data in MUMC+HISs.

To measure low-level timeliness, numerous effectiveness indicators and goals were found in the literature. Prior research indicated that 20 minutes is a maximally acceptable waiting time for an outpatient’s clinic visit from a patient perspective (American Medical News, 2013). This was taken as the preliminary low-level timeliness performance indicator. Additionally, the Dutch Treeknorms could be used for setting high-level timeliness goals (Dutch ministry of Health, Welfare and Sports, 2005). Treeknorms could easily be implemented using the existing data in the central hospital information system. This was uncertain for the waiting times within examination visits (see also subsection 3.3.4).

To measure continuity, it was possible using the information in the MUMC+’ HISs to check whether the same medical specialist or junior doctor performed two (or several) activities. This could be used as a performance indicator(s). Since surgeries are the main medical interventions in the cataract treatment process, it was suggested to research surgical (dis)continuity.

The set of preliminary performance indicators and the matching healthcare quality domains are given in Table 3. Note that the internal quality domains efficiency and safety are not present in Table 3. Efficiency is often not deemed very important by patients (Detsky, 2011). Safety, from a patient perspective, is strongly related to clinical effectiveness (the absence of complications) and partially covered by the clinical effectiveness indicator volume of cataract treatments performed per surgeon, since this volume relates to the adverse event rate.

<table>
<thead>
<tr>
<th>Quality domain</th>
<th>Preliminary performance Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clinical effectiveness</td>
<td>Volume of cataract treatments performed per surgeon</td>
</tr>
<tr>
<td>Timeliness</td>
<td>1. Waiting time in examination visits (low-level)</td>
</tr>
<tr>
<td></td>
<td>2. Treeknorms (high-level)</td>
</tr>
<tr>
<td>Demand-orientation</td>
<td>Surgical continuity</td>
</tr>
</tbody>
</table>

Third, the relevance of investigating the patient priorities timeliness and continuity and the chosen preliminary performance indicators for the MUMC+ cataract treatment process and its
patient population was checked in the pre-analysis. It was assumed that investigating clinical effectiveness is always relevant for a clinical treatment process.

3.3.3. Pre-analysis

In this pre-analysis a relevant part of the existing and validated QUESTIONnaire for cataract patients (Nivel, 2001) was used. The QUOTE questionnaire focuses on the cataract patients’ perception of quality of care and consists of 15 generic indicators (items) and 16 cataract-specific indicators (items). Timeliness and care continuity were (amongst others) measured in this questionnaire. This questionnaire was already in Dutch and permission to use it was obtained from the copyright holders. An example item is the waiting time was more than 15 minutes (during a visit). The QUOTE questionnaire uses a 4-point Likert scale (1 = this was not the case at all up to 4 = yes, this was the case). In total there were 30 positively formulated items (a higher score is better) and one negatively formulated item. An example of a positively formulated item is the treating physician has enough time for me. The negatively formulated item is the waiting time was more than 15 minutes. The used questionnaire is given (in Dutch) in Appendix C. The questionnaire was distributed to 40 cataract patients at their final postoperative examination, distributed over two Mondays (23 on the first Monday, 17 on the second Monday). The patients were asked to fill in the questionnaire themselves. In case of sight problems either a partner, family member or friend helped by reading the questions out loud. A priori it was determined that positively formulated items that on average scored lower than 3 and negatively formulated items that scored on average higher than 2, were considered interesting and relevant to possibly further investigate in this thesis project.

All responses were entered in an Excel spreadsheet to obtain descriptive statistics. Missing values varied between 0 and 25% of all respondents per item. The missing values were deleted pairwise. All available values per item were thus used, resulting in a minimal sample size of 30 per item (in the case of 25% missing values). Descriptive statistics are given in Appendix D. There were three items that were interesting and relevant to further research in this thesis project. Two of these were positively formulated and scored on average lower than 3. The other one was negatively formulated and scored on average higher than 2. This were the items (1) waiting time was more than 15 minutes, (2) interim information is given about the time to surgery and (3) the ophthalmologist is always the same person. Further consultation with patients, the first company supervisor and additionally through observation confirmed issues on these items. With respect to the item ‘the ophthalmologist is always the same person’ it was found that especially surgical continuity is important for the MUMC+ cataract patients. With respect to interim information, patients expected more information about the (time to) surgery and room for their questions during their consults. Time pressure, directly associated with the waiting times, was most likely the cause of this experienced lack of information and room for questions.

Concluding, based on the pre-analysis the patient priorities timeliness and care continuity are found to be directly relevant for the MUMC+ cataract treatment process. With respect to timeliness, especially low-level timeliness (timeliness within examination visits) seems an issue.
This enlarges the probability of finding differences between patient groups within the process mining analysis that focuses on low-level timeliness and furthermore it might enlarge the practical value of this research. With respect to care continuity especially surgical continuity seems important to the MUMC+ patient population. Investigating this might also enlarge the practical value of this research. High-level timeliness is investigated as well in this thesis project, since this gives an indication of the logistical pressure on the whole treatment process and thus also on the (examination) visits. Now concrete goals were chosen. The amount of goals per domain was limited to one or two, due to the limited research time scope.

3.3.4. MUMC+ cataract treatment process effectiveness framework

For the quality domain clinical effectiveness the indicator volume of cataract treatments was included. A concrete goal (cut-off point) for this indicator was set on 250 surgeries per surgeon per year, based on the literature finding on adverse event rates (subsection 2.3.2) in combination with data restrictions (see subsection 3.4).

For the quality domain timeliness the maximally acceptable waiting time of 20 minutes was included as preliminary indicator for the examination visits (low-level timeliness). It was chosen to focus specifically on the preoperative and final postoperative examination visits, two important visits that represent the begin and end of the cataract treatment process. When investigating the data during the log inspection step in the process mining investigation, it was found that only throughput times of examination visits were reliable and waiting times could not be distinguished from treatment times. Therefore, goals for the throughput time of the preoperative and postoperative were consulted with the first hospital supervisor. For the preoperative examination, the planned treatment time is 60 minutes. If one adds the found maximally acceptable waiting time of 20 minutes, a proper benchmark for the throughput time is 80 minutes. For the final postoperative examination the planned treatment time is 20 minutes. Adding again the maximally acceptable waiting time, gives a proper benchmark for the throughput time of 40 minutes.

For analysing the high-level timeliness, the Dutch national Treknorms for outpatient procedures were used. The norm for the maximum time between referral and the preoperative examination (diagnostics) is four weeks and 80% of all patients should be diagnosed within 3 weeks (Dutch ministry of Health, Welfare and Sports, 2005). The norm for the maximum waiting time between referral and an actual outpatient treatment is seven weeks and 80% of all patients should be treated within 5 weeks (Dutch ministry of Health, Welfare and Sports, 2005). As a result, the norm for the maximum waiting time between pre-operative examination and an actual outpatient treatment is three weeks. This last norm was used in this thesis. Note that the 80%-norms are more strict in practice, but that they do not tell for each independent case whether it was either executed successfully or unsuccessfully from a timeliness point-of-view: it depends on the timeliness of other cases. The maximum waiting time norms do provide a single cut-off point per case (patient).
For the demand-orientation quality domain the performance goal used was same medical specialist or junior doctor performs both surgeries. This indicator gives information on care continuity in two important process steps of the cataract treatment process and can easily be investigated using the data in the MUMC+’ HISs. The complete MUMC+ cataract treatment process effectiveness measurement framework is given in Table 4.

<table>
<thead>
<tr>
<th>Quality domain</th>
<th>Effectiveness Indicators</th>
<th>Effectiveness Goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clinical effectiveness</td>
<td>Volume of cataract treatments performed per surgeon</td>
<td>More than 250 surgeries per surgeon per year</td>
</tr>
<tr>
<td>Timeliness</td>
<td>1. Throughput time preoperative examination visit</td>
<td>Less than 80 minutes</td>
</tr>
<tr>
<td></td>
<td>2. Throughput time final postoperative examination visit</td>
<td>Less than 40 minutes</td>
</tr>
<tr>
<td></td>
<td>3. Waiting time for surgery</td>
<td>Less than three weeks</td>
</tr>
<tr>
<td>Demand-orientation</td>
<td>Surgical continuity</td>
<td>Same medical specialist or junior doctor performs both surgeries</td>
</tr>
</tbody>
</table>

3.4. Data requirements
The basic data requirements for a process mining investigation are (1) information about occurred events, (2) timestamps for these events and (3) information about the originators of these events. At MUMC+ these basic data requirements are registered in the central hospital information system (SAP i.s.h.med). This information system was thus the data source for this thesis project. Note that the described data gathering problems due to scattered and independently developed/ customized IT systems (subsection 2.2.2) were not encountered since a central hospital information system, containing all relevant information, is used at MUMC+.

3.5. Data collection
The information in SAP is organised as a relational database: a set of tables, containing information, that are coupled via keys (primary and foreign). Important tables for this investigation were the

1. **Appointments table**—this table contains all the scheduled appointments
2. **Diagnoses table**—this table contains the diagnosis and the care status
3. **Case movements table**—this table contains information about outpatient visits and inpatient stays
4. **Employee role table**—this table contains information about the organisational role of each employee
5. **Patient table**—this table contains basic information about patients (such as age, sex etcetera)
6. **Services performed table** — this table contains information about services performed for/on patients

7. **SAP change log tables**—these tables contain detailed information about changes made to the tables within SAP.

The **occurred events** used in this research are registered at three levels of detail: (1) **case movement-level**, (2) **service performed-level** and (3) **change log-level**. A case movement is an interaction between a patient and a healthcare provider and it is defined at a low-level of detail (Mans, 2013). Examples are an inpatient stay, a consultation by phone or an outpatient visit. As part of a movement, multiple health services can be performed on/for a patient. Services have a shorter duration than case movements and represent a concrete set of acts, e.g. performing an eye test (Mans, 2013). SAP change logs contain highly detailed information about changes made (to files) within SAP, as detailed as a change made to a patient’s registered surname. Highly precise timestamps are registered for these changes. These registration levels are not strictly hierarchal. An UML diagram is given in Figure 6. A service performed registration is always tied to one case movement. One case movement consists of zero or multiple registered services performed. A change in SAP information can be tracked back to zero or one case movement, depending on whether it was a change to information tied to a case movement (for example a patient status within a visit) or to a change in general information, such as the patient age. A case movement contains one to multiple SAP information changes. Note that there can also be link(s) between SAP information change(s) and a performed service (e.g. a change in information tied to a specific service), but this was not considered in this thesis project.

![Figure 6: UML diagram registration of occurred events](image)

**Figure 6**: UML diagram registration of occurred events

**Timestamps** are recorded at all three levels. At the **case movement-level** the **planned date** offered valuable time information. Since case movements are directly tied to the Appointments table in SAP, their (high-level) time information is very reliable. For every record in the case movements-table in SAP the begin and end time (on a planned date) were exactly the same, so this offered no additional information.

At the **service-performed level**, the begin and end time (on a planned date) were exactly the same for each record as well. So only the **planned date** was valuable. Since multiple services can be registered for a case movement, the level of detail was higher than at the case-movement level. At the **change log level**, **visit status changes** offer more detailed time information within a case movement. Visit statuses are used for internal logistics purposes within a patient visit. The visit status change registration is theoretically accurate to seconds. It is worthy to notice that change logs potentially offer low-level time information which can enhance the relevance of process mining results. Hereby this thesis project can also contribute to the identified challenge on **timestamp level of granularity** (see subsection 2.2.2). The correctness of these timestamps
has a large influence on the practical and scientific relevance of using (SAP) change logs information and is determined in the low-level timeliness analysis (section 4.2). Since visit statuses are used for internal logistics within a patient visit, it was hypothesized that the timestamps would in general be correctly registered.

Event **originators** are well recorded at the service performed-level, which is obligatory, and not at all at the case movement level. Event originators are recorded at the change log level as the logged-in computer users at the computer at which the visit status change is made. Therefore, event originators were taken into account on the service performed-level and on the change log level. This naturally has an influence on the analysis-level choice per process mining analysis, i.e. a preference for not using the case movement level where possible.

The required data was extracted from the hospital information system on the 22nd of April with help of the second academic supervisor, Ronny Mans. He had access to all required tables, except for the SAP change logs. Information from the SAP change logs was extracted in cooperation with personnel from the Medical Information Technology (MiT) department of MUMC+ from a SAP back-up (containing information up to the 22nd of February 2012). All data was anonymized for privacy reasons. From the extracted data a Microsoft Access 2010 database was constructed. This database formed the input for the analysis phase.

### 3.6. Research scope restrictions

This research was restricted to the **cataract treatment process**. For each patient their treatment process was taken into account from their **pre-operative examination** date (**process start**) until the patient had its **final postoperative examination** (**process end**). On the change log level, only the visit status changes belonging to the case movements ‘preoperative examination’ and ‘final postoperative examination’ were taken into account. Furthermore, only patients that had their process starting point after the 1st of October 2012 were taken into account. The date of data extraction was the 22nd of April 2013, so only data registered before this date was taken into account. The starting point was chosen since the cataract treatment process was significantly restructured in September 2012. By taking this time scope, only patients that (theoretically) went through exactly the same treatment process were considered. The volume of cataract treatments is approximately 1250 per year at MUMC+. Note that most patients receive two cataract treatments (one per eye) and the amount of distinct patients is thus a lot lower than 1250 per year (but larger than 625 per year). Given this high yearly volume, the used timeframe offered a sufficiently large dataset for performing process mining and for drawing statistically valid conclusions for group differences.
4. Process mining analyses

This chapter covers the analysis phase of this thesis project. The process mining analyses are organised per investigated healthcare quality domain. For timeliness a separate high-level timeliness analysis (focus on the whole treatment process) and low-level timeliness analysis (focus on an examination visit) were conducted. The structure of this chapter is given in Figure 7. For each process mining analysis the process mining methodology introduced in section 3.1 was used.

![Figure 7: Structure process mining analyses](image)

4.1. Demand orientation analysis

Demand orientation process effectiveness was investigated by investigating surgical continuity, as discussed in chapter 3 (Methodology). Beforehand, the level of analysis was determined. As mentioned in subsection 3.4 occurred events are registered at three levels at MUMC+. In the Microsoft Access database it was found that originators are only reliably registered at the service performed-level. Therefore, this analysis level was the only option for this analysis and chosen. The main questions that are answered in this analysis are applied versions of the research sub-questions and as follows

### Demand orientation analysis questions

1. Is there a difference in the ordering and frequency of activities between patients that had surgical continuity and patients that had surgical discontinuity? (control-flow perspective)
2. Is there a difference in resource involvement between patients that had surgical continuity and patients that had surgical discontinuity? (organisational perspective)
3. Is there a difference in time-related performance between patients that had surgical continuity and patients that had surgical discontinuity? (performance perspective)

4.1.1. Log preparation

Log preparation was done in Microsoft Access. Queries were used within Microsoft Access for creating the event log. The steps carried out and the accompanying queries can be found in respectively Appendices E and F. The final output in Microsoft Access was a table containing the following columns: (1) patient, (2) timestamp, (3) performed service, (4) performing person and (5) organisational role of the performing person. Subsequently the final output from Microsoft Access was exported to a Microsoft Excel spreadsheet. From Microsoft Excel it could be directly imported in the process mining tool Disco. In the Disco import tool, the column ‘patient’ was
selected as the cases, the column ‘timestamp’ as timestamps, the column ‘performed service’ as events and the columns ‘performing person’ and ‘organisational role of the performing person’ as originators.

4.1.2. Log inspection

Log inspection was carried out in Disco. In total, the event-log contained 2396 events, 185 cases (patients), 82 distinct events (activities) and 51 resources. Especially the amount of distinct events was noticeable, since it concerns the registration of services performed. One would expect more uniformity regarding the distinct activities that are performed. The level of granularity of the pieces-of-work is determinant too however. The average amount of events per case was approximately 14. A preliminary process model was derived in Disco, see Figure 8.

In this process model the activities ‘cornea-corneatopografie’ and ‘oog-IOL-master’ refer to eye scans performed during the preoperative examination. The services ‘Dagverpleging-zwaar’ (heavy day time nursing), ‘oogl.-extractaps. Impl. Lens.a.o.k.’ (eye lens extraction and implanting a new lens), ‘Snijtijd enkelvoudige zitting’ (making an incision in a surgical session in which only cataract is treated) and ‘Zittingduur enkelvoudige OK’ (being in surgical session in which only cataract is treated) refer to services performed on the day of surgery. The number ‘1’ was added in Microsoft Access to the names of these services for the second health case, in which the second surgery is registered, to distinguish these from the same services for the first health case. ‘Telefonisch consult’ refers to a consultation by phone. ‘Eindcontrole’ refers to the final postoperative examination. The recorded frequency of the activities and paths in the event-log is given respectively in the activity boxes and on the arcs in Figure 8. In total 13 activities are in the preliminary process model and the other distinct activities (69 in total) are not in the model.

Note in Figure 8 that the frequencies on the outgoing arcs of ‘Zittingduur enkelvoudige OK’ are relatively small compared to the other arc frequencies. Further investigation revealed that this has to do with the multitude in registered services performed. Next to the direct arc from ‘Zittingduur enkelvoudige OK’ to ‘Dagverpleging-zwaar 1’ and the arc via ‘Telefonisch consult’ there are other arcs going from ‘Zittingduur enkelvoudige OK’ to ‘Dagverpleging-zwaar 1’ via other not frequently registered intermediate activities, with among others ‘Vervolgconsult algemeen’ (general continuation consultation), ‘1e consult algemeen’ (first general consultation) and ‘sp. Eisende hulp contact buiten de sehaf’ (contact with the. The same holds for the low frequencies on the outgoing arcs of ‘Zittingduur enkelvoudige OK 1’. This has either to do with (variety in) the way activities are registered or the diversity in the occurred actions.

It was determined that the surgery service Dagverpleging-zwaar was most suitable for constructing patients groups in Disco, since this surgery service should be recorded for all surgeries and was in practice most often registered. For by far most cases, the originator was identical for all four surgery services. If this was not the case, it was impossible to determine the correct originator-registration. The originator of Dagverpleging-zwaar was then thus chosen.

4.1.3. Constructing groups

Two separate event logs were created. The first event log consisted of patients that had two surgeries by the same surgeon (surgical continuity). The second event log consisted of patients that had two surgeries by two different surgeons (surgical discontinuity).
In total there were 170 patients in the preliminary event log for which the activity ‘Dagverpleging-zwaar’ was eventually followed by the activity ‘Dagverpleging-zwaar 1’. Note that there were 185 patients in the dataset, so for 15 patients their ‘Dagverpleging-zwaar (1)’ registration was not complete. Of these 170 patients, 106 patients had surgical continuity and 64 patients surgical discontinuity. The point-estimate for the percentage of patients that had surgical continuity, a performance indicator for care continuity, was thus approximately 62% in this patient sample (106 divided by 170). A 95% confidence interval for this percentage (proportion) gives the following boundaries for the patient population 55%-69% (Newcombe, 1998). Subsequently the two created event logs were further analysed and compared to shed light on the possible link between process execution and process effectiveness. Three process mining perspectives—the control-flow perspective, the organisational perspective and the time perspective were explored.
4.1.4. Control-flow analysis

The ordering and frequency of events in the two groups of patients were compared. The control-flows are depicted in Figure 10 (surgical discontinuity, group 1) and Figure 9 (surgical continuity, group 2). The main difference between the control-flows is that surgical sessions are in group 1 more often registered as single sessions (‘Enkelvoudige zitting’). These are sessions in which only cataract is treated. Only for approximately 10% of the patients a combination session, a session in which cataract and (an)other health problem(s) are simultaneously treated, is registered. For patients of group 2 approximately 30% of the patients had combination sessions and approximately 70% single sessions. Apart from this, the control-flows show little differences in ordering and frequency. The lower arc frequencies on some arcs have either to do with (variety in) the way activities are registered or the diversity in the occurred actions.
4.1.5. Organisational analysis

The registered services *Dagverpleging-zwaar* and *Dagverpleging-zwaar 1* for each patient and the registered *originators* of these activities lie at the basis of the organisational analysis. The analysis was started in Disco. Two function types are originators of the surgeries in the event log, (1) *medical specialist* and (2) *junior doctor*. Frequency information was exported from Disco and subsequently imported into Microsoft Excel for further investigation. Over-all, approximately 77% of all surgeries are performed by medical specialists and 23% is performed by junior doctors. Interestingly, this distribution significantly differs in the created patients groups. If there was surgical continuity, approximately 88% of these surgeries are performed by medical specialists and 12% by junior doctors. If there was surgical discontinuity, approximately 61% of all surgeries is performed by medical specialists and 39% by junior doctors. These insights, including 95% confidence intervals (CI’s) are summarised in Table 5. Concluding, there is a statistical difference in function involvement between both patients groups. The confidence intervals do not overlap.

<table>
<thead>
<tr>
<th>Group</th>
<th>Percentage medical specialist</th>
<th>Percentage junior doctor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surgical continuity</td>
<td>88% (95% CI 83%-93%)</td>
<td>12% (95% CI 8%-17%)</td>
</tr>
<tr>
<td>Surgical discontinuity</td>
<td>61% (95% CI 53%-69%)</td>
<td>39% (95% CI 31%-47%)</td>
</tr>
<tr>
<td>Over-all</td>
<td>77% (95% CI 73%-81%)</td>
<td>23% (95% CI 19%-27%)</td>
</tr>
</tbody>
</table>

4.1.6. Time analysis

The time-related performance was analysed using Disco, Excel and SPSS. Disco was used to provide raw time per performance estimates to determine whether further, more precise and valid, investigation within Excel and SPSS was viable. The total throughput time (time between the pre-operative examination and the final postoperative-examination) was investigated. Furthermore, the process was split in three mutually exclusive time intervals, using four process milestones, as visualized in Figure 11 (the numbers represent the time intervals). These time intervals were investigated separately as well. To make the abovementioned process splits in Disco, the milestone activity *cornea-corneatopografie* was used as a proxy for the pre-operative examination, since this activity was best registered for the pre-operative examination in the event log. Milestone activities *Dagverpleging-zwaar* and *Dagverpleging-zwaar 1* were used for respectively the first surgery and the second surgery for the same reason. The milestone appointment ‘Eindcontrole’ (final postoperative examination) from the Appointments table in SAP was used to represent the final postoperative examination, since often no service was registered for the final postoperative examination.

In Disco it was found that the average throughput time was 73 days if there was surgical discontinuity (Group 1). The average throughput time was 76 days if there was surgical continuity (Group 2). Subsequently the results were exported to Excel and from there imported into SPSS. In SPSS outliers in both groups were detected using boxplots. An outlier was defined...
as a value that was more than 1.5 times the Inter Quartile Range (IQR) off the boxplot border. This method was used throughout the thesis project. After outlier removal the average throughput time was 68 days for group 1 (standard deviation = 11) and 73 days for group 2 (standard deviation = 18). Kolmogorov-Smirnov tests indicated that the values in group 2 were normally distributed (P = .087), but values in group 1 were not normally distributed (P = .000). Levene’s test of homogeneity of variances indicated that the variances in both groups significantly differed (P = .001). Since the assumptions of One-Way ANOVA, equal variance per group and normally distributed data within groups, were clearly not fulfilled, a non-parametric Welch test was done to test the difference in means. This test indicated that the difference in means was not significant at a 95% confidence level (P = 0.082). All time analysis findings are summarised in Table 6 (one row per investigated time interval). The average time between the pre-operative examination and the first surgery was 15 days in Disco for group 1 and 24 days for group 2. The averages were respectively 15 days (standard deviation = 9 days) and 23 days (standard deviation = 15 days) after removing outliers in SPSS. The data was not normally distributed within both groups and the variance in both groups differed significantly. The difference in means was significant (P = .001). Concluding, there is a difference in time related performance between patients that have either surgical continuity or discontinuity.

Table 6: Time analysis results (demand orientation analysis)

<table>
<thead>
<tr>
<th>Time interval</th>
<th>Group 1 (discontinuity)</th>
<th>Group 2 (continuity)</th>
<th>Statistical difference tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Throughput time</td>
<td>• Mean: 68 days</td>
<td>• Mean: 73 days</td>
<td>• Levene’s test (P = .001)</td>
</tr>
<tr>
<td></td>
<td>• St. dev: 11 days</td>
<td>• St. dev: 18 days</td>
<td>• Welch test (P = .082)</td>
</tr>
<tr>
<td></td>
<td>• Not normally distributed (P &lt; .05)</td>
<td>• Normally distributed (P = .087)</td>
<td></td>
</tr>
<tr>
<td>Pre-operative examination→First surgery</td>
<td>• Mean: 15 days</td>
<td>• Mean: 23 days</td>
<td>• Levene’s test (P = .002)</td>
</tr>
<tr>
<td></td>
<td>• St. dev: 9 days</td>
<td>• St. dev: 15 days</td>
<td>• Welch test (P = .001)</td>
</tr>
<tr>
<td></td>
<td>• Not normally distributed (P &lt; .05)</td>
<td>• Not normally distributed (P &lt; .05)</td>
<td></td>
</tr>
<tr>
<td>First surgery→Second surgery</td>
<td>• Mean: 15 days</td>
<td>• Mean: 16 days</td>
<td>• Levene’s test (P = .141)</td>
</tr>
<tr>
<td></td>
<td>• St. dev: 4 days</td>
<td>• St. dev: 4 days</td>
<td>• Welch test (P = .307)</td>
</tr>
<tr>
<td></td>
<td>• Not normally distributed (P &lt; .05)</td>
<td>• Not normally distributed (P &lt; .05)</td>
<td></td>
</tr>
<tr>
<td>Second surgery→Final postoperative examination</td>
<td>• Mean: 34 days</td>
<td>• Mean: 35 days</td>
<td>• Levene’s test (P = .260)</td>
</tr>
<tr>
<td></td>
<td>• St. dev: 6 days</td>
<td>• St. dev: 6 days</td>
<td>• Welch test (P = .534)</td>
</tr>
<tr>
<td></td>
<td>• Not normally distributed (P &lt; .05)</td>
<td>• Not normally distributed (P &lt; .05)</td>
<td></td>
</tr>
</tbody>
</table>

The time between the two surgeries was on average 21 days in Disco for group 1 and 18 days in Disco for group 2. After removing outliers in SPSS, the average was 15 days in group 1 (standard deviation = 4 days) and 16 days in group 2 (standard deviation = 4 days).
The data was not normally distributed within both groups and the variance in both groups did not differ significantly. The difference in means was not significant (P = .001).
The time between the second surgery and the final postoperative examination was on average 37 days in Disco for group 1 and 36 days in Disco for group 2. After removing outliers in SPSS, the averages were respectively 34 days (standard deviation = 6 days) and 35 days (standard deviation = 6 days) in group 1 and group 2. The data was not normally distributed within both groups and the variance in both groups did not differ significantly. The difference in means was not significant (P = .534).

4.1.7. Evaluation of process mining results

The main analysis findings are summarized in Figure 12. These findings were discussed with the first hospital supervisor. One of the causes for these findings is the current surgery planning policy. The current policy is to try to schedule the same medical specialist in the surgery roster every other week in order to facilitate both surgical continuity for the patient and a minimal time between the two surgeries (14 days). This surgery planning policy can explain the high percentage of patients that have both surgeries by the same surgeon, due to the emphasis on surgical continuity in the policy. A negative consequence of the desired surgical continuity is an increased average time between the pre-operative examination and the first surgery (and the higher variance). This most likely has to do with planning flexibility: it is easier to treat a patient as soon as possible if the patient can be scheduled at two different surgeons (more planning options) than if the patient is to be scheduled at the same surgeon. Furthermore, a triage system is in place. The simplest cases (category 1) can be treated by junior doctors. The medium cases (category 2 and 3) are always treated by medical specialists and both surgeries are preferably done by the same specialist. The most complicated cases of cataract (category 4) are always treated by one medical specialist, who is the only one authorized for these surgeries. The triage system can explain the found difference in function involvement per group and the distribution of combination sessions among the patient groups. Since only the triage-category 1 patients can be treated by junior doctors, these cases need to be distributed among all junior doctors. It thus rarely happens that the same junior doctor treats the same patient twice, hereby explaining the found difference in function involvement. Combination sessions are always performed by medical specialists and due to the emphasis on surgical continuity in the surgery planning policy they occur more often in the surgical continuity group.

![Figure 12: Main findings demand orientation analysis](image)

Process mining techniques helped in this analysis to give insight into the link between the execution of the cataract treatment process and its effectiveness with respect to surgical continuity. Especially the organisational and time perspective were useful.
4.2. Timeliness analysis

Timeliness process effectiveness was investigated by researching the effectiveness indicators waiting time for surgery (high-level timeliness analysis) and the throughput time during the preoperative and final postoperative examination visits (low-level timeliness analysis), as discussed in chapter 3 (Methodology). Beforehand, the levels of analyses were determined.

In the Microsoft Access database it was found that case movements are more consistently registered for patients than services performed. It seemed to occur that a case movement (e.g. a patient visit) is registered without accompanying registered services performed. The fact that the Appointments table in SAP is directly coupled to the Case movements table can explain the consistency in case movement registration. Therefore, the case movement level seemed most appropriate for investigating the waiting time for surgery (in days). For investigating the throughput time of the examination visits, the only possible level of analysis was the change log level. Therefore, the change log level was chosen for this analysis.

4.2.1. High-level timeliness analysis

In this subsection the process effectiveness indicator waiting time for surgery is investigated. The main questions that are answered in this analysis are applied versions of the research sub-questions and as follows

<table>
<thead>
<tr>
<th>High-level timeliness analysis questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Is there a difference in the ordering and frequency of activities between patients that were treated within 21 days after their pre-operative examination and after 21 days? (control-flow perspective)</td>
</tr>
<tr>
<td>2. Is there a difference in time-related performance between patients that were treated within 21 days after their pre-operative examination and after 21 days? (time perspective)</td>
</tr>
</tbody>
</table>

Note that there is no sub-question with respect to resource involvement, since the organisational perspective cannot be investigated in an analysis on the case movement level.

4.2.1.1. Log preparation

Log preparation was again done in Microsoft Access. The selection steps carried out are given in Appendix G. All (help-)queries used to derive this final output from the SAP tables are given in Appendix H. The final output in Microsoft Access was a table containing the following columns: (1) patient, (2) event and (3) timestamp. Note that originators are not registered on the case movement level. In the Disco import tool, the column ‘patient’ was selected as the cases, the column ‘events’ as events and the column ‘begin date’ as timestamps.

4.2.1.2. Log inspection

Log inspection was carried out in Disco. In total the event-log contained 3138 events, 514 cases (patients) and 19 distinct events (activities). The average amount of events per case was approximately 6. Since the level of granularity is low, the low average amount of events was as expected. A preliminary process model was derived in Disco. The model is given in Figure 13.
The activity ‘Bezoek’ refers to a patient visit, ‘Tel. Consult’ to a consultation by phone and ‘Operatie’ to a surgery. These are the basic activities (case movements) registered. Within Microsoft Access again a ‘1’ was added to the names of all case movements that are registered for the second health case. Furthermore, the preoperative and final examination visit were marked by adding respectively ‘oog-IOL-master’ and ‘EC’. This was needed to distinguish these process milestones from the other visits. The marking was done using the registration of the service ‘oog-IOL-master’ and the appointment for the final postoperative examination.

In Figure 13 two main orderings of events are visible, in line with the general planning of surgeries and examination visits (given in Appendix A). The first describes the process for patients that had one surgery. Their process starts by either a visit or the preoperative examination: there is no uniform process start. Subsequently, they have their first surgery (activity ‘Operatie’) followed by either a visit or a consultation by phone (the day after). This is followed by another visit (a week after surgery) and the process is finalized by the final postoperative examination (‘Bezoek EC’). This pattern is visible in the upper side of Figure 13, surrounded by the dotted line. The second ordering of events describes the process for patients that had two surgeries. Their process starts in the same manner as the process for patients that just had one surgery. Only after the visit a week after surgery, their second surgery (‘Operatie 1’) is their next activity and not the final postoperative examination. After the second surgery there is a consultation by phone or visit, followed by another visit and the process is finalized by the final postoperative examination (‘Bezoek 1 EC’). The second surgery and the following activities are depicted in the lower side of Figure 13 (outside the dotted line).

There are two deviations in the preliminary process model from these main orderings. Firstly, sometimes visits are incorrectly registered as final examination visits. This leads to outgoing arcs from these visits (since their timestamp is not the ‘last in line’). Secondly, sometimes the examination visit(s) after the first surgery are registered as ‘Bezoek 1’. This means that these activities are sometimes registered within the second health case. These registration errors and the frequency of occurrence were fed back to the department.
4.2.1.3. Constructing groups

Groups of patients were created based on the time between the preoperative examination and the first surgery. In total there were 228 patients that followed the arc from ‘Bezoek oog-IOL-master’ to ‘Operatie’. 131 out of these patients had their first surgery within 21 days (approximately 57% of all patients) (group 1). The others had their first surgery after 21 days and the Treeknorm was thus not accomplished for these patients (group 2).

4.2.1.4. Control-flow analysis

The ordering and frequency of activities was compared between the two groups of patients. In Figure 15 the control-flow of group 1 is depicted. In Figure 14 the control-flow of group 2 is depicted. The ordering of activities is in both groups almost the same as in the preliminary process model (Figure 13). The arrow from ‘Bezoek’ to ‘Bezoek 1’ forms the exception. Most likely this concerns a matter of registration: cases for which the week examination is registered in the second health case. It was hypothesized that the presence or absence of a clinical visit before the preoperative examination might influence the time between the preoperative examination and the first surgery, since in an early stadium more information about the (severity of the) health case would be available and the patient can be scheduled earlier. This was investigated using the frequency of occurrence of a prior visit within each patient group. When patients were treated within 21 days, 50 out of 131 patients had a registered visit prior to the preoperative examination (38%, 95% CI 30% - 46%). When patients were treated after 21 days, 33 out of 93 patients had a registered visit prior to the preoperative examination (35%, 95% CI 27% - 46%). The confidence intervals clearly overlap, so there is no statistical indication that the presence of a clinical visit before the preoperative examination reduces the time to the first surgery.
4.2.1.5. Time analysis

The time-related performance was analysed again using Disco, Excel and SPSS. Disco was used to provide raw time performance estimates to determine whether further, more precise, investigation within Excel and SPSS was viable. Here only the values found in SPSS, after outlier removal, are given. The same process milestones and outlier removal method as in the demand orientation analysis were used here. The average throughput time was 61 days for group 1 (standard deviation = 9 days) and 81 days for group 2 (standard deviation = 15 days). The variance in both groups differed significantly \((P = .001)\). The values were not normally distributed and the means differed significantly \((P = .000)\), which was expected based on the performance indicator choice.

The average time between the preoperative examination and the first surgery was 11 days for group 1 (standard deviation = 5) and 33 days for group 2 (standard deviation = 11) after outlier removal. The variance and mean differed significantly between both groups \((P = .000)\). The high average and variation within group 2 gave cause to further investigate the over-all distribution of the time between diagnostics and the first surgery. Over-all the average time between diagnostics and the first surgery was 20 days (standard deviation = 13) after outlier removal. The distribution is positively skewed. A histogram is given in Figure 16. Since the average is very close to the Treeknorm of 21 days and the standard deviation is relatively high (the variation coefficient is .65), it follows that almost half the patients are not treated within the time norm, as found when creating patient groups.

![Histogram time between preoperative examination and the first surgery](image)

**Figure 16:** Histogram time between preoperative examination and the first surgery

The average time between the two surgeries was 15 days in group 1 (standard deviation = 4) and 14 days in group 2 (standard deviation = 1). The variance differed significantly between both groups \((P = .000)\). Furthermore, the means differed significantly \((P = .043)\), indicating a difference in time-related performance that was not directly expected based on the performance indicator choice. The average time between the second surgery and the final postoperative examination was found to be 35 days for both groups in both groups within Disco. This time interval was not further investigated in Excel and SPSS.

4.2.1.6. Evaluation of process mining results

The main analysis findings are summarized in Figure 17. The control-flow analysis did not result in explicit interesting findings and an organisational analysis was not possible on the case movement level.
These findings were discussed with the first hospital supervisor. The low proportion of people that are treated within 21 days after the pre-operative examination most likely has to do with the high inflow of patients in the cataract treatment process (approximately 1250 per year) in combination with the used surgery planning policy, in which there is an emphasis on surgical continuity (hereby limiting the planning possibilities). The found statistical difference in average and variance in the time between both surgeries can most likely be explained by the fact that most patients that were treated within 21 days after the pre-operative examination experienced surgical discontinuity and most patients that were treated after 21 days after the pre-operative examination experienced surgical continuity, in line with the conclusion of the demand orientation analysis. In the demand orientation analysis it was found that the surgeon was most often a medical specialist if there was surgical continuity. Since in the surgery planning it is tried to schedule medical specialists every other week and this is not explicitly done for junior doctors, it is logical that the average and variance in time between surgeries are a bit lower for patients that were treated after 21 days. Note that although the difference in average time between groups is statistically significant, its impact on the throughput time is minimal: only one day difference on average. Process mining techniques helped in this analysis to give insight into the link between the execution of the cataract treatment process and its effectiveness with respect to (high-level) timeliness. Especially the time perspective was useful.

4.2.2. Low-level timeliness analysis

Here the low-level timeliness analysis is outlined. The main questions that are answered in this analysis are applied versions of the research sub-questions and as follows

<table>
<thead>
<tr>
<th>Low-level timeliness analysis questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Is there a difference in the ordering and frequency of activities between patients that had a throughput time of 80 and 40 minutes or less in respectively the pre-operative and final postoperative examination and patients with a longer throughput time?</td>
</tr>
<tr>
<td>2. Is there a difference in organisational resource involvement between that had a throughput time of 80 and 40 minutes or less in respectively the pre-operative and final postoperative examination and patients with a longer throughput time?</td>
</tr>
<tr>
<td>3. Is there a difference in time-related performance between patients that had a throughput time of 80 and 40 minutes or less in respectively the pre-operative and final postoperative examination and patients with a longer throughput time?</td>
</tr>
</tbody>
</table>
4.2.2.1. Log preparation

Log preparation was done in Microsoft Access. Queries were used within Microsoft Access for creating two separate event logs: one event log for the pre-operative examination visit (event-log 1) and one event log for the final postoperative examination visits (event-log 2). The steps carried out to create the event logs are given in Appendix I. All (help-)queries used to derive this final output from the SAP tables are given in Appendix J. The final output in Microsoft Access was two tables containing the columns: (1) patient, (2) change in visit status and (3) time. In the Disco import tool, the column patient was selected as the cases, the column change in visit status as events and the column time as timestamps.

4.2.2.2. Log inspection

Log inspection was carried out in Disco. In total event-log 1 contained 763 events, 171 cases (patients) and 18 distinct events (activities). Event-log 2 contained 1312 events, 289 cases and 20 distinct events (activities). The average amount of events per case was 4. This occurred for 120 out of 171 cases in event-log 1 and in 204 out of 243 cases in event-log 2, indicating a clear main-flow. Preliminary process models were derived for both event-logs in Disco.

The three most registered visit changes were ‘Gepland → Wachtend’ (in English: Planned → Waiting), ‘Wachtend → In behandeling’ (in English: Waiting → In treatment) and ‘In behandeling → Behandeling voltooid’ (in English: In treatment → Treatment finished). These are given in blue in Figure 18. Additionally, the planned start time of the visit is given in blue as well (Geplande begintijd). These blue activities form the main process flow (thick arcs). Less frequent, deviant, status changes are given in grey. It is important to know to which process milestones the three most registered visit statuses correspond. This matter was discussed with Figure 18: Preliminary process model pre-operative examination.
the first hospital supervisor and two other graduate students, who did process time measurements and observed the process within preoperative and final examination visits. The main process milestones and the corresponding visit statuses are depicted in Figure 19.

Average throughput time pre-operative examination Disco: 101 minutes
Average throughput time pre-operative examination measurements: 101 minutes
Average throughput time final postoperative examination Disco: 58 minutes
Average throughput time final postoperative examination measurements: 53 minutes

The status change Planned $$\rightarrow$$ Waiting corresponds to the point in time when a patient checks in at the registration desk. It is used to notify the optometrist that a patient has arrived. The status change Waiting $$\rightarrow$$ In treatment corresponds to the point in time when the optometrist is done with all measurements. This status change notifies the junior doctor that a patient is ready to be received by him/her for a consult. The status change In treatment $$\rightarrow$$ Treatment finished corresponds to the moment in time when the junior doctor is done with the patient. The throughput time measurements and the found averages in Disco are given in Figure 19 as well (upper side). Note that the averages found in Disco seem fairly consistent with the measurements (reality). This provides some evidence that timestamps on this high-level of granularity can indeed be accurate (process mining data-gathering challenges, subsection 2.2.2) It was chosen to focus on the process throughput times, since treatment and waiting times could not be separated from each other with the currently registered visit status changes.

Figure 19: Main process steps examination visit

Figure 20: Preliminary process model final postoperative examination
In Figure 20 the preliminary process model for the final examination visits is given. The same main process flow can be identified as in Figure 18 (in blue). The less frequently occurring visit status changes given in Figure 18 and 20 signify a problem. When the visit status is incorrectly set, another resource in the process is given incorrect logistical information about where the patient is in the process. The visit status change **in treatment → Waiting** is especially dangerous, since the status ‘Waiting’ is a valid visit status but results in the situation were a patient is waiting for the junior doctor but the doctor is expecting that the patient did not have their eye measurements yet. This status change occurred at approximately 10% of all patients at both examination visits (as measured by the fraction of outgoings arcs 18/165 = 11% and 25/242 =10%). The visit status ‘Gemeld’ (in English: Checked-in), see Figure 18 and 20, is less dangerous since it is not a valid visit status. This status should not be used, so it is easier to detect that an error has been made. Since most deviant visit statuses originate from the correct visit status ‘In treatment → Waiting’, these were further investigated in the control-flow, organisational and time analysis. Furthermore, note that approximately 10% of patients is too late for their appointment **at the preoperative examination** (14/136 = 10%) and approximately 24% at the **final postoperative examination** (57/239 = 24%).

4.2.2.3. Constructing groups

Groups were created based on **benchmarks for the throughput time of a preoperative and final postoperative visit**. Throughput time was defined as the time between the **planned start of a visit** and the visit status change **In treatment → Treatment finished**. If a patient thus arrives earlier than the planned start of a visit, the time until the planned start is not seen as part of the throughput time, since the hospital has no influence on this time interval. The benchmark for the pre-operative visit was **80 minutes**. The benchmark for the final examination visit was **40 minutes**. In total there were 171 patients in event log 1. Out of these 171 patients, 33 patients were treated within 80 minutes and 138 patients had a throughput time larger than 80 minutes (benchmark accomplished for approximately 19% of all patients). In total there were 289 patients in event log 2. Out of these 289 patients, 61 patients were treated within 40 minutes and 228 patients had a throughput time larger than 40 minutes (benchmark accomplished for approximately 21% of all patients).

4.2.2.4. Control-flow analysis

For the preoperative examination visit the ordering and frequency of activities is depicted in Figure 22 for the group of patients that were treated within 80 minutes (**group 1**) and in Figure 21 for the group of patients that had a throughput time larger than 80 minutes (**group 2**). The main (correct) flow of visit status changes is for both groups identical. The **amount of deviant visit status changes** is higher in the second group (5 in group 1 versus 22 in group 2, as measured by the outgoing arcs from Waiting → In Treatment) indicating that there might be a relationship between the occurrence of a deviant visit status change and the throughput time. However, the corresponding amount of correct visit changes in the second group is larger as well (28 in group 1 versus 119 in group 2), which is logical since there are more patients in group 2 than in group 1. A Fisher’s exact test indicated that there was no evidence for a higher frequency of deviant visit status changes in either group (P = 1.000).

For the final postoperative examination the ordering and frequency of activities is depicted in Figure 24 (treated within 40 minutes, **group 1**) and Figure 23 (throughput time larger than 40
minutes, group 2). The main flow is identical for both groups. The amount of deviant visit status changes is a lot higher in the second group (1 in group 1 versus 57 in group 2, as measured again by the outgoing arcs from Waiting → In Treatment) indicating that there might clearly be a relationship between the occurrence of a deviant visit status change and the throughput time.

However, the amount of corresponding correct visit status changes in the second group is larger as well (43 in group 1 versus 175 in group 2), which is logical again since there are more patients in group 2 than in group 1. A Fisher’s exact test indicated that there is statistical evidence for unequal frequencies in both groups (P = .000). The impact size of deviant visit changes on the throughput time was further investigated in the time analysis (subsection 4.2.2.6). Process mining techniques helped in the control-flow analysis to detect deviant visit status changes and to find differences in the frequencies of these visit status changes between patient groups. Statistics was needed to find proof for different frequencies in both groups.
4.2.2.5. Organisational analysis

From the discussions it was already known which organisational resource is responsible for which visit status change. The receptionist is responsible for the visit status change Planned $\rightarrow$ Waiting, the optometrist for the status change Waiting $\rightarrow$ In treatment and the junior doctor for the status change In treatment $\rightarrow$ Treatment finished. Most deviant visit status changes clearly occur as outgoing arrows from Waiting $\rightarrow$ In Treatment (see Figure 21 up to 24). The most likely explanation is that the optometrists sometimes change the visit status from Waiting to In treatment at the beginning of the eye measurements (instead of at the end of the measurements), which seems logical to do, and perform an additional visit status change at the end of the eye measurements (In treatment$\rightarrow$Waiting or In treatment$\rightarrow$Checked-In). In Disco it was checked how often the same originator both performed the visit status changes ‘Waiting$\rightarrow$In treatment’ and ‘In treatment$\rightarrow$Waiting’ in final postoperative examination visits. This was the case in 96% of the cases (24/25), as measured by the outgoing arcs of ‘Waiting$\rightarrow$In Treatment’. The same was done for the visit status changes ‘Waiting$\rightarrow$In treatment’ and ‘In treatment$\rightarrow$Checked-in’ in final postoperative visits. This was the case in 94% of the cases (32/34), as measured again by the outgoing arcs of ‘Waiting$\rightarrow$In treatment’. This finding supports the most likely explanation that the optometrist is responsible for the deviant visit status changes originating from the visit status change ‘Waiting$\rightarrow$In Treatment’.

4.2.2.6. Time analysis

The average throughput time of preoperative examination visits was 101 minutes (standard deviation = 38). A Kolmogorov-Smirnov test indicates that the distribution is approximately normally distributed (P = .200). A histogram is given in Figure 25.

There appear to be some outliers on both sides: there are unrealistically short and long throughput times. After outlier removal the average throughput time was 97 minutes (standard deviation = 32). Note that the average is still a lot larger than the benchmark value (80 minutes). The average throughput time of final post-operative examination visits was 58 minutes (standard deviation = 42). A Kolmogorov-Smirnov test indicated that the values were not normally distributed (P = .000). A histogram is given in Figure 26. There appeared to be clear outliers (on both sides). After outlier removal, the average was 53 minutes (standard deviation = 26 minutes). Note that this is exactly the value that the other graduate students measured. The values were still not normally distributed (P = .000).
The impact size of deviant visit status changes on the throughput time for final postoperative examination visits was further investigated in the time analysis, since the Fisher’s exact test indicated in the control-flow analysis that there was a significant difference in frequency of deviant visit status changes between patient groups. Two groups were created: the first group consisted of patients for which the deviant visit status changes In Treatment → Checked-in and In treatment → Waiting were not present and the second group consisted of patients for which one (or both) of these deviant visit status changes was present. The average throughput time of the first group was 50 minutes (standard deviation = 24 minutes). The average throughput time of the second group was 65 minutes (standard deviation = 18 minutes). Levene’s test indicated that the variance was not equal in both groups (P = .045). The non-parametric Welch test indicated that the means were unequal (P = .000). Concluding, deviant visit status changes correlate with significantly higher throughput times. It is most likely that deviant visit status changes cause longer throughput times, since visit status changes are used for internal logistics. This lengthening effect is on average 15 minutes. Process mining techniques helped in the time analysis to provide preliminary insight into the throughput times of the examination visits and the impact size of deviant visit status changes on the throughput time for final postoperative examination visits. Further, precise, research within SPSS was required however to obtain accurate time estimations and to draw valid conclusions.

4.2.2.7. Evaluation of process mining results

In the log inspection it was found that cases on average have four activities: three correct visit status changes and the planned visit start. Deviations seem to occur quite often: for approximately 10% of all patients. Furthermore, the percentage of patients that were late for their appointment (for whatever reason) was quite striking: 23% for final postoperative examination visits. In the medical literature the focus is especially on no-show rates (broken appointments), of which being too late is a subset. In an academic outpatient practice an average no-show rate of 23.1% (without reminders) was found (Parikh et al., 2010), which is quite in line with this finding on patients that arrive too late.

When constructing groups it was found that only 19% of all the patients were treated within the 80 minutes benchmark for the preoperative examination visit and only 21% of all the patients were treated within the 40 minutes benchmark for the final postoperative examination visit. In the control-flow analysis it was found that deviations occur statistically more often in the group of patients that was not treated within the benchmark time, indicating a relationship between deviations and the throughput time. In the organisational analysis it was found that most deviations are most likely done by optometrists. In the time analysis the throughput time averages were compared with the benchmarks. They differed to a large extent. Furthermore, it was found that deviant visit status changes correlate with higher throughput times and the lengthening effect is on average 15 minutes. These results were discussed with the first hospital supervisor. The visit status protocol should be communicated again clearly and the amount of deviant visit status changes should be checked periodically. The low percentage of patients that is treated within the benchmark time is in line with the results of the pre-analysis (subsection 3.3): waiting times tend to be high and high time pressure is experienced during the visits. Further research into causes is needed and described in Chapter 7 (Discussion and recommendations). Process mining techniques helped in this analysis to give insight into the link between the execution of the cataract treatment process and its effectiveness with respect to low-level timeliness. Especially the control-flow and time perspective were useful.
4.3. Clinical effectiveness analysis

Clinical effectiveness was investigated by creating two patient groups based on the volume of cataract surgeries per surgeon, as discussed in chapter 3 (Methodology). Beforehand, the level of analysis was determined. As mentioned in subsection 3.4, originators are only reliably registered at the services performed level. Therefore, this analysis level was chosen. The main questions that are answered in this analysis are as follows

Clinical effectiveness analysis questions

1. Is there a difference in the ordering and frequency of activities between patients that were treated by either a high- or low-volume surgeon? (control-flow perspective)
2. Is there a difference in resource involvement between patients that were treated by either a high- or low-volume surgeon? (organisational perspective)
3. Is there a difference in time-related performance between patients that were treated by either a high- or low-volume surgeon? (performance perspective)

4.3.1. Log preparation

Log preparation was done in Microsoft Access. The steps carried out to prepare the event log are given in Appendix K. The final output in Microsoft Access was a table containing the following columns: (1) patient, (2) timestamp, (3) performed service, (4) performing person and (5) organisational role of the performing person. All (help-) queries used to derive this final output from the SAP tables are given in Appendix L. In the Disco import tool, the column patient was selected as the cases, the column timestamp as timestamps, the column performed service as events and the columns performing person and organisational role of the performing person as originators.

4.3.2. Log inspection

Log inspection was carried out in Disco. In total the event-log contained 5382 events, 514 cases (patients, 329 with one surgery and 185 with two surgeries), 115 distinct events (activities) and 60 resources. Especially the amount of distinct events was noticeable, since it concerns the registration of different services performed and one would expect more uniformity in the registration. The average amount of events per case was approximately 10. A preliminary process model was derived in Disco. The model is given in Figure 27. The model contains 15 out of the 115 distinct activities and shows that patients can enter the main process in two manners: directly (no prior visit before the pre-operative examination) or via an earlier visit (consultation, ‘Vervolgconsult algemeen’in Figure 27). Furthermore, it shows the clear split between patients that underwent one surgery within the researched timeframe (direct arc between ‘Zittingduur enkelvoudige OK’ and ‘Eindcontrole’) and the patients that had two surgeries (activities in between ‘Zittingduur enkelvoudige OK’ and ‘Eindcontrole’) within the researched timeframe.

Most activity names were already translated in the demand orientation analysis. New are the activities ‘15A385’ (code for the care product ‘removing a cataract’), ‘Dummy kosten tijdstip’ (dummy activity for the point in time at which (lens) costs are received from patients) and ‘eerste pkl. Bezoek-administratief tarief’ (first polyclinic visit; administrative tariff).
4.3.3. Constructing groups

Groups were created based on the **volume of cataract surgeries per surgeon**, in line with literature. The goal (cut-off point) used was 250 surgeries per surgeon per year, as set out in Chapter 3. Since only data from approximately 29 weeks was used, this norm was pro rata set on **139 surgeries**. Note that surgeons might also perform surgeries in other healthcare institutions. This was not taken into account, since no insight could be gained on this matter. This means that the found volumes are a lower-limit of the true volume per surgeon within the researched timeframe. Two surgeons in the dataset performed more than 139 surgeries each within the researched timeframe as measured by the surgery service Dagverpleging-zwaar. In total 199 patients had both surgeries by a high-volume surgeon (**group 1, high-volume surgeon**). The other group consists of 19 surgeons who performed less than 139 surgeries each, 289 patients had both surgeries by a low-volume surgeon (**group 2, low-volume surgeon**). Note that the total amount of patient for which the service Dagverpleging-zwaar is registered is thus 488, a bit lower than the 514 cases in the event log.

![Figure 27: Preliminary process model clinical effectiveness analysis](image-url)
4.3.4. Control-flow analysis

The ordering and frequency of events in both groups was investigated. It was hypothesized that the main ordering and activity frequencies would most likely not differ per group due to the low adverse event rates (see Chapter 2). This turned out to be. It was interesting however to look at the registration of services that indicate the occurrence of a complication. For all performed services it was determined if they could logically be an indicator for the occurrence of a complication. This was the case for: Contact with the emergency department (‘spoed eisende hulp contact buiten seahard’), Hospitalization (‘opname ziekenhuis’), Stitching a wound (‘huid-wond hechten’), Stitching the cornea (‘cornea-hechten perforatie’) and Ablatio (‘glas.lich.pars plan vitrect. bij ablatio’). The frequency of occurrence was measured as the amount of outgoing arcs from the surgery service registration (Dagverpleging-zwaar) to the investigated service in specially created process models that only contained the surgery service ‘Dagverpleging zwaar’ and the investigated service. The results are given in Table 7.

<table>
<thead>
<tr>
<th>Service performed</th>
<th>Occurrence in group 1 (high volume; 199 patients)</th>
<th>Occurrence in group 2 (low volume; 289 patients)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contact with the emergency</td>
<td>8</td>
<td>14</td>
</tr>
<tr>
<td>Hospitalization</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Stitching a wound</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Stitching the cornea</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Ablatio</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Fisher’s exact tests were performed for all services in Table 7 in order to find possible between group differences. No significant differences were found. Note that the low adverse event rate in both groups (4.1 % in group 1; .2 % in group 2) makes it very hard to find statistically valid differences. For example the expected frequency of an adverse event during process execution in group 1 is .398 (.002 times 199 patients) and in group 2 is 1.156 (.004 times 289 patients). To find statistically valid differences for groups of cataract patients, if existing, most probably data from a larger time span is required. Another complicating factor is the fact that all triage-category 4 cases are treated by a high-volume surgeon: the case-mix differs between groups.

4.3.5. Organisational analysis

It was interesting to have a look at the organisational functions of the surgeons per group. In group 1 (high volume) both surgeons were medical specialists. In group 2 (low volume) there were 19 surgeons, out of which 7 were medical specialists and 12 were junior doctors: a clear difference per patient group. The distribution of surgeries among medical specialists (split in high and low volume) and junior doctors is given in Figure 28. This information is evaluated in the evaluation subsection (4.3.7) and helps to explain the findings of the time analysis.
4.3.6. Time analysis

The performance from a time perspective was analysed using Disco, Excel and SPSS. The total throughput time was investigated and the process splits created in the demand orientation analysis were used here as well. For the preoperative examination, the oog-IOL-master service registration was used as a dummy. For the surgeries the service Dagverpleging-zwaar was used and for the final postoperative examination the appointment Eindcontrole. The services used were chosen since they were the most registered services performed for respectively the preoperative examination and the surgeries.

The average time between the preoperative examination and the first surgery was **19 days** for **group 1** (high-volume) (standard deviation = 11 days) and **18 days** for **group 2** (low-volume) (standard deviation = 15 days) after outlier removal. Levene’s test indicated that the variance differed significantly between groups (P = .003). The non-parametric Welch test indicated that the averages did not differ significantly between groups (P = .428). All time analysis findings are summarised in Table 8 (one row per investigated time interval). The average time between both surgeries was **15 days** for **group 1** (high-volume) (standard deviation = 3 days) and also **15 days** for **group 2** (low-volume) (standard deviation = 3 days) after outlier removal. The variance did not differ significantly between groups (P = .061). Since both groups were not normally distributed, the non-parametric Welch test was performed again to determine if the group averages differed significantly. This was not the case (P = .203).

<table>
<thead>
<tr>
<th>Time interval</th>
<th>Group 1 (high-volume)</th>
<th>Group 2 (low-volume)</th>
<th>Statistical difference tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Throughput time</td>
<td>• Mean: 65 days</td>
<td>• Mean: 75 days</td>
<td>• Levene’s test (P = .000)</td>
</tr>
<tr>
<td></td>
<td>• St. dev: 8 days</td>
<td>• St. dev: 18 days</td>
<td>• Welch test (P = .000)</td>
</tr>
<tr>
<td>Pre-operative examination→</td>
<td>• Mean: 19 days</td>
<td>• Mean: 18 days</td>
<td>• Levene’s test (P = .003)</td>
</tr>
<tr>
<td>First surgery</td>
<td>• St. dev: 11 days</td>
<td>• St. dev: 15 days</td>
<td>• Welch test (P = .428)</td>
</tr>
<tr>
<td>First surgery→Second surgery</td>
<td>• Mean: 15 days</td>
<td>• Mean: 15 days</td>
<td>• Levene’s test (P = .061)</td>
</tr>
<tr>
<td></td>
<td>• St. dev: 3 days</td>
<td>• St. dev: 3 days</td>
<td>• Welch test (P = .203)</td>
</tr>
<tr>
<td>Second surgery→Final</td>
<td>• Mean: 34 days</td>
<td>• Mean: 35 days</td>
<td>-</td>
</tr>
<tr>
<td>postoperative examination</td>
<td>(Disco)</td>
<td>(Disco)</td>
<td></td>
</tr>
</tbody>
</table>

The average throughput time was **72 days** for **group 1** (standard deviation = 21) and **76 days** for **group 2** (standard deviation = 20) before outlier removal. Levene’s test indicated that the variances were statistically equal in both groups (P = .681). The non-parametric Welch test was
done since the values were not normally distributed in both groups and indicated that the group averages were statistically equal ($P = .328$). Interestingly, after outlier removal, the group averages were respectively 65 days for group 1 (standard deviation = 8) and 75 days for group 2 (standard deviation = 18 days). Levene’s test indicated that the variance was not statistically equal in both groups ($P = .000$) and the non-parametric Welch test indicated that the group averages were not statistically equal ($P = .000$). However, the found throughput time average for group 1 after outlier removal seemed very low compared to the found throughput times in the other process mining analyses. The large difference in average throughput time before and after outlier removal in group 1 most likely has to do with the outlier removal method. Since the IQR-value is relatively low for group 1 (16 in group 1, compared to 26 in group 2), values are easily marked as outliers. A boxplot (before outlier-removal) is given in Appendix M. Nonetheless, since the 95% confidence interval boundaries for the group average of group 2 are 70 and 80 days, the groups’ averages most likely differ significantly even if outliers are removed somewhat more conservatively than done now using the IQR.

### 4.3.7. Evaluation of process mining results

Groups were created based on the volume of cataract surgeries per surgeon. In the control-flow analysis the ordering and frequency of events in both event-logs was investigated. The ordering of activities did not differ per group. With respect to the frequency of activities the services were investigated that indicate the possible occurrence of a complication, since this is strongly related to clinical effectiveness. No significant differences per group were found.

In the organisational analysis it was found that the two surgeons in group 1 were medical specialists and out of the 19 surgeons in group 2, 7 were medical specialists and 12 were junior doctors. The distribution of surgeries was as follows: (1) 143 surgeries were performed by junior doctors, (2) 242 surgeries were performed by low-volume medical specialists and (3) 286 surgeries were performed by high volume medical specialists. Combining this knowledge with knowledge on triage-categories used at MUMC+, it is highly likely that the 143 surgeries performed by junior doctors were all of triage-category 1, since junior doctors may only perform category 1 surgeries. The 242 surgeries performed by low-level medical specialists are likely a mix of triage-category 2 and 3, since these surgeries are always performed by medical specialists, category 1 is in very high demand among junior doctors and the only medical specialist who is performing surgery on category 4 patients is a high-volume medical specialist, which was verified. The 286 surgeries performed by high-volume medical specialists are likely a mix of triage-category 2, 3 and 4. As a result, the patient group with a low-volume surgeon is likely a mix of triage-category 1, 2 and 3 and the patient group with a high-volume surgeon is likely a mix of triage-category 2, 3 and 4. The case-mix thus clearly differs per patient group.

In the time analysis it was found that the variance in the time between diagnostics and the first surgery differed significantly between groups. This was discussed with the second university supervisor and the most likely cause is the difference in case-mix between both groups. Additionally, the average and variance in throughput time differed significantly (after outlier removal). This was discussed with the second university supervisor as well and the most likely explanation is again the difference in case-mix. Some further research into the case-mix and the triage-categories was carried out after all initial process mining results were integrated and evaluated (Chapter 5). In Chapter 5 this additional research is described.
5. Evaluation and additional research

In the process mining analyses the cataract treatment process at MUMC+ was investigated. The starting point of the investigated process was set on the pre-operative examination and the end point was set on the final postoperative examination. Three process mining analyses focused on the high-level process: (1) the demand orientation analysis, (2) the high-level timeliness analysis and (3) the clinical effectiveness analysis. One process mining analysis, the low-level timeliness analysis, zoomed in on the preoperative and postoperative examination visits. Within each process mining analysis, three perspectives were investigated (if possible): the control-flow, organisational and time perspectives. Here the process mining results are integrated and jointly evaluated. Furthermore, some additional research that resulted from the evaluation is described. This chapter is split in three subsections: the first subsection discusses the high-level process evaluation, the second subsection discusses low-level process evaluation and the third subsection describes the performed additional research.

5.1. High-level process

The cataract treatment process at MUMC+ is characterised from a **logistics point of view** by a **high yearly inflow of patients** (approximately 1250 patients). The treatment process is characterized from an **organisational point of view** by a **surgery planning policy** in which **surgical continuity** is central and a **tripe-policy** with four different categories. The different triage-categories differ with respect to the (organisational role of the) surgeon allowed to perform the surgery and the emphasis on surgical continuity, as mentioned in the prior evaluation subsections. These logistic and organisational characteristics of the cataract treatment process at MUMC+ were central in evaluating and explaining the process mining findings with process owners in the separate analyses.

In the demand orientation analysis a **lengthening effect of surgical continuity on the time between the preoperative examination and the first surgery was discovered**. The most likely cause for this difference is the increased **planning flexibility** if there is no surgical continuity: it is harder to schedule a patient for two surgeries at the same surgeon as soon as possible than at two different surgeons, especially if one takes the high yearly inflow patients into account and the influence that this inflow of patients has on the **planning possibilities**. Furthermore, in the demand orientation analysis a significant **difference in the function of organisational resources involved** between the group of patients with surgical continuity and the group of patients with surgical discontinuity was found. This could be explained by the fact that junior doctors may only treat health cases of **tripe-category 1** and these cases are in high demand among junior doctors (the availability is scarce). It thus rarely happens that the same junior doctor treats the same patient twice. Patients that had surgeries by junior doctors thus often experienced surgical discontinuity. In the surgery schedule of medical specialists it is tried to schedule the same specialist every other week, in order to facilitate surgical continuity. This contributes to the high amount of patient that experienced surgical continuity. The following insights into the link between the cataract treatment execution and its effectiveness was gained

<table>
<thead>
<tr>
<th>Demand orientation analysis insights</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Surgical continuity (demand orientation effectiveness) interacts with timeliness: trade-off</td>
</tr>
<tr>
<td>2. Surgical continuity is influenced by the surgery planning policy and the triage policy</td>
</tr>
</tbody>
</table>
In the high-level timeliness analysis it was discovered that 57% of all patients have their surgery within 21 days after their pre-operative examination and thus made the Treeknorm. The most likely explanation for this low score is the combination of a high yearly inflow of patients (process external factor), which has an influence on the planning possibilities for surgeries, in combination with the emphasis on surgical continuity (process internal factor). The latter is in line with the finding of the demand orientation analysis that surgical continuity interacts with timeliness: there is a trade-off. This insight also offers the opportunity to possibly increase the percentage of people that have their first surgery within the Treeknorm: put less emphasis on surgical continuity for health cases where this is possible. The following insights into the link between the cataract treatment execution and its effectiveness was gained

<table>
<thead>
<tr>
<th>High-level timeliness analysis insights</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The score on the Treeknorm most likely results from the high yearly inflow of patients (external factor) in combination with the emphasis on surgical continuity (internal factor)</td>
</tr>
<tr>
<td>2. The score can possibly be improved by putting less emphasis on surgical continuity</td>
</tr>
</tbody>
</table>

In the clinical effectiveness analysis no differences in clinical effectiveness between patient groups was discovered. In Chapter 7 (Discussion and recommendations) a reflection is given on this matter. However, it was discovered that two surgeons performed more than 139 surgeries (high-volume surgeons) and these surgeons are medical specialists. Nineteen surgeons performed less than 139 surgeries (low-volume surgeons) and out of these 19 surgeons, 7 were medical specialists and 12 were junior doctors. Furthermore, a) difference in throughput time was discovered. The most likely cause is the difference in case-mix: the patient group with a high-volume surgeon is likely a mix of triage-categories 2, 3 and 4, the patient group with a low-volume surgeon is likely a mix of triage-categories 1, 2 and 3. It would be interesting to create separate patient groups for all triage-categories and to check for between-group differences in order to provide more insight in the case-mix difference and its consequences for timeliness.

Some additional research was performed and this is described in subsection 5.3. The following insights into the link between the cataract treatment execution and its effectiveness was gained

<table>
<thead>
<tr>
<th>Clinical effectiveness analysis insights</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Patients that were treated by a high-volume surgeon had on average a shorter throughput time than patients that were treated by a low-volume surgeon</td>
</tr>
<tr>
<td>2. The patient case-mix of high-volume and low-volume surgeons differed</td>
</tr>
</tbody>
</table>

5.2. Low-level process (examination visits)
On this level the throughput times of the preoperative and final examination visits were examined. The constructed benchmarks (40 minutes for the final postoperative examination and 80 minutes for the preoperative examination) were not accomplished for the majority of patients. The high yearly inflow of patients (external factor) in the cataract treatment process and as a result the high number of patients within the process puts a strain on (planning) the examination visits. From an organisational point of view, deviant visit status changes, most likely done by optometrists, contribute to the large throughput times. Lowering the amount of deviant visit status changes, e.g. by clarifying the visit status policy, can lower the throughput
times. However, after removing these cases from the dataset, the average throughput time was still a lot larger than the benchmark time. **Further investigation is required** to find other causes. It is possible that the planned treatment times are too short. Lastly, it was also found that the fraction of patients that are too late for their examination visit, either due to arriving too late or queuing, is 23% for final examination visits, which is high but in line with medical literature. The impact of this on the logistical process performance should be further researched. The following insights into the link between the cataract treatment execution and its effectiveness was gained.

### Low-level timeliness analysis insights

1. **The low score on the benchmark times results from a variety of causes**
2. **The high yearly inflow of patients (external factor) most likely contributes to the low score**
3. **Deviant visit status changes contribute to the low-score and are most likely done by optometrists. Lowering the amount of deviant visit status changes can improve the score on the benchmark throughput times**
4. **Further investigation into other causes is required**
5. **The fraction of patients that is too late for their appointment is high but in line with medical literature**

### 5.3. Additional research

During evaluation of the combined process mining results with the second university supervisor, it was discussed that there might also be a difference in time between the preoperative examination and the first surgery between patients that had surgery by either a medical specialist or a junior doctor and experienced either surgical (dis)continuity. The reasoning was that this could occur due to the difference in patient case-mix, resulting from the triage-policy.

<table>
<thead>
<tr>
<th>Medical specialist(s) as surgeon</th>
<th>Junior doctor(s) as surgeon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surgical continuity</td>
<td>Average: 23 days</td>
</tr>
<tr>
<td>Surgical discontinuity</td>
<td>Average: 19 days</td>
</tr>
</tbody>
</table>

This was analysed within SPSS. The found averages per group are given in Table 9. A difference was found within the group of patients with surgical discontinuity. A One-way ANOVA was conducted since the assumptions with respect to normality within groups and equal group variance were met. It indicated that the difference in group average was statistically significant (\( P = .035 \)). No statistical difference was found within the group of patients with surgical continuity (One-Way ANOVA, \( P = .087 \)). This most likely has to do with the low amount of patients that had both surgical continuity and were treated by a junior doctor. The found difference can be explained by the **triage-policy**: the junior doctors only treat health cases of **triage-category 1** and these are in **high demand**, which results in short waiting times for surgery. The medical specialists that treat patients without surgical continuity, treat health cases of triage-category 2 and 3 (a **case-mix**). These cases are not scarce, leading to higher waiting times for surgery.
It was also discussed that it would be interesting to create separate patient groups for the different triage categories. It was impossible to uniquely identify each triage-group within the data extracted from the HIS however. The result of the triage-process was not available within the created dataset. It is known however, that junior doctors only treat triage-category 1 health cases and that low-volume medical specialists treat triage-category 2 and 3 surgeries. The high-volume surgeons most likely treat a mix of triage-category 2, 3 and 4. Furthermore, in the dataset it was found that patients treated in both surgeries by a high-volume medical specialist always experienced surgical continuity. Based on the combination of surgeon volume in both surgeries (high/low), surgical continuity and organisational role of the surgeon in both surgeries, five unique patient groups can be created for further statistical analysis that represent a (mix of) triage-category(s). These are given in Table 10. The two groups with surgical discontinuity were already analysed above (see Table 9 for the found average times).

Table 10: Created patient groups with time to surgery averages (additional research part 2)

<table>
<thead>
<tr>
<th>Surgical Continuity</th>
<th>Medical Specialist(s) as Surgeon in Both Surgeries</th>
<th>Junior Doctor(s) as Surgeon in Both Surgeries</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-volume surgeon</td>
<td>(Average: 18 days)</td>
<td>-</td>
</tr>
<tr>
<td>Low-volume surgeon</td>
<td>(Average: 34 days)</td>
<td>Low-volume surgeon (Average: 13 days)</td>
</tr>
<tr>
<td>Surgical Discontinuity</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Low-volume surgeon</td>
<td>(Average: 19 days)</td>
<td>Low-volume surgeon (Average: 13 days)</td>
</tr>
</tbody>
</table>

The other three groups were created in Disco and subsequently analysed in SPSS. The found average times between the preoperative examination and the first surgery are given in Table 10. A graphical overview is given in Appendix N. The non-parametric Welch test (ANOVA assumptions were not met) indicated a significant difference in average time between high- and low-volume medical specialist surgeons (surgical continuity) (P = .008). A One-way ANOVA indicated a significant difference in average time between low-volume medical specialists and junior doctors (surgical continuity) (P = .004). No difference was found between high-volume specialists and low-volume junior doctors (surgical continuity).

These findings can help in explaining the found differences in the average and variance of the throughput time between patients that were treated by either a high- or low-volume surgeon in both surgeries: especially the patient group with surgical continuity treated by a low-volume medical specialist increases the variance and average of the entire low-volume patient group. This can most likely be explained by the limited planning possibilities of low-volume medical specialists, especially if surgical continuity is required. Furthermore, the patients of triage-category 1, treated by junior doctors, have an impact on the variance as well.

The findings of this additional research can be used as well to sharpen the advice on how to improve the average time between the preoperative examination and the first surgery. It is especially interesting to try to minimize the group of patients that were treated in both surgeries by the same low-volume medical specialist. Lastly, note that process mining was not applied in this additional research. The inspiration for the additional analyses originates from the process mining analyses however.
6. Conclusion
The research question that drove this research was

Main research question
Can process mining techniques help in determining the link between the execution of a clinical treatment process and its effectiveness?

This research was of an exploratory nature: one case study on the treatment process of cataract (at MUMC+) was conducted to obtain initial insights in the usefulness of applying process mining techniques for discovering the link. The research sub-questions used were

Research sub-questions
1. Can process mining techniques help in determining the link between the ordering and frequency of activities of a clinical treatment process and its effectiveness? (control-flow)
2. Can process mining techniques help in determining the link between the resource involvement in a clinical treatment process and its effectiveness? (organisational)
3. Can process mining techniques help in determining the link between the time-related performance of a clinical treatment process and its effectiveness? (time)

The control-flow perspective was only to some extent useful in the process mining analyses that focused on the high-level treatment process— the demand orientation, high-level timeliness and clinical effectiveness analysis. There were little differences found in the ordering of events between the investigated patient groups. Differences in event frequencies were more interesting however to investigate at the high-level treatment process level. When focusing on the event frequencies, between group differences are easily numerically observable. For example the frequency of possible complications. Note that when focusing on event frequencies, the process view is clearly less relevant then when focusing on the ordering of events. It is merely comparing numbers between groups, with the possible addition that an event should occur before/ after a certain other event (e.g. a complication after a surgery).

In the low-level timeliness analysis the control-flow perspective was very useful. The ordering of events pointed at deviant visit status changes and where in the process this occurred. The event frequencies gave insight into the gravity of the situation. Combined, they triggered further performance research into these deviant visit status changes. Concluding, over-all the control-flow perspective contributed in determining the link between process execution and the process effectiveness of the investigated clinical treatment process. Especially the event frequencies proved useful in this investigation.

The organisational perspective proved very useful in the process mining analyses. Since event originators were only reliably registered for services performed, it was particularly useful in the analyses that were performed on this level— the continuity and clinical effectiveness analysis. The organisational function of the originators of surgeries was used. Two main organisational functions were involved: the medical specialist and the junior doctor. Organisational policy is often coupled to organisational functions. In the performed case study the surgery planning policy and the triage policy could explain differences in organisational function involvement in
created patient groups. By combining this insight with found time performance differences between patient groups, some interesting consequences of current policy were found. For example the negative effect of surgical continuity, a corner stone of the current surgery planning policy, on the time between the pre-operative examination and the first surgery.

In the low-level timeliness analysis process knowledge, gained from discussions (with process owners), could be used to point out the most likely responsible organisational function for the deviant visit status changes. This should not be used to punish these persons, but this knowledge can be used for (partially) preventing future deviant visit status changes and hereby to improve the process execution and performance. Concluding, the organisational perspective was very useful for determining the link between the execution of a process and its effectiveness in the performed process mining analyses. Especially looking at the involvement of organisational functions proved useful.

The time perspective proved very useful in the process mining analyses as well. It was used in the analyses to point out possibly interesting differences in throughput times and in the demand orientation, high-level timeliness and clinical effectiveness analysis additionally to point out possibly interesting differences in throughput time within pre-defined process parts (e.g. the time between both surgeries). The process mining software used (Disco) could however only give the preliminary indication that there might be a time difference between patients groups. It was not possible to provide (statistical) evidence for the existence of the difference. Furthermore, it was not possible to delete outliers that (unfairly) influenced the average values found in Disco. To be able to do both things, additional analyses in a statistical software package were required (SPSS was used in this research). Concluding, the time perspective was very useful for determining the link between process execution and process effectiveness. The insights gained within process mining were of an exploratory nature. Further analysis within a statistical software package was required to provide solid evidence for the existence of found differences between groups.

In addition, discussions with process owners were often required to be able to make sense of the found differences between patient groups and to provide (additional) process knowledge. This greatly helped in this process mining investigation. The discussions together with the process mining results also triggered some additional research, which in turn helped to make even more sense of the found differences between patient groups. Over-all, one can conclude that process mining can certainly help in determining the link between process execution and process effectiveness. Process mining is however only one tool out of the toolbox for determining the link between process mining and process effectiveness. By combining process mining with other tools, such as statistics and discussions with process owners, a rich understanding of the link can be gained for the investigated process and process improvement opportunities can be identified. Just as the different process mining perspectives can complement each other, different (scientific) methods/tools can also complement each other.

This research is novel since it is the first process mining case study that focuses specifically on process effectiveness. It shows that by operationalizing process effectiveness based on well-chosen performance indicators that are relevant (to patients), very useful insights can be gained on the link between the execution of a clinical process and its effectiveness. It also shows some limitations of process mining in investigating this link: it cannot provide hard numerical evidence or the theory behind/reason for found differences.
7. Discussion and recommendations

The case study performed was of an exploratory nature. Naturally, more studies are required to find more solid evidence for the usefulness of deploying process mining techniques for determining the link between process execution and process effectiveness. This study provides an excellent starting point however, since links between process execution and process effectiveness were found for different process effectiveness performance indicators.

The cataract treatment process was chosen since this process is clinically straightforward, well academically researched, well documented at MUMC+ and the high patient volume makes statistical analysis of process mining results possible. Looking back at this decision, one can conclude that this decision impacted this research both positively and negatively. Positively, since it was possible to find between group differences in the analyses that gave useful insights. Furthermore, it was possible to find hard, statistical, evidence for the group differences. Negatively, since no insight was gained on the link between process execution and clinical outcomes, only on the link between process execution and the clinical experience. This most likely has to do with (1) the very low adverse event rates, (2) the absence of uniform clinical outcome measures for cataract (case-based) and (3) the fact that the process is clinically straightforward (relatively little process variance). In future process mining studies that focus especially on clinical effectiveness, a go/no-go decision could be made based on these three factors. In these future process mining studies, it was hypothesized that patient reported outcome measures might be used. To test this, the Catquest-9SF questionnaire (given in Appendix B) was distributed to 183 patients that had cataract surgery on both eyes within the researched timeframe. 99 questionnaires were returned. The average of the items was taken and was 3.56 (on a scale of 1 to 4). The standard deviation was .458. Since the average was high and there was very little variation in responses, it was concluded that it is likely not viable to structurally capture this data for creating patient groups for process mining purposes.

With respect to process execution, it was assumed that the three investigated process mining perspectives give a balanced picture of process execution. Process execution can be viewed broader however—for example by focusing explicitly on the decisions taken within the execution of a process and on the data involved (the data perspective). The possibilities to investigate process executions are naturally limited by the limits of process mining techniques. There are some process mining techniques however that also specifically focus on the data perspective. Future research could take the data perspective into account.

With respect to process effectiveness, clear design choices were made to be able to perform this research. The healthcare quality domains were chosen as the theoretical basis. Furthermore, the patient perspective was chosen. Literature on patient priorities was consulted to identify matters which are important to patients in general. Furthermore, a selection process consisting of several steps (see Chapter 3) was conducted in order to be able to distinguish patient priorities, performance indicators and concrete goals that apply to and matter to the MUMC+ cataract patient population.

Furthermore, the measures needed to be practically measurable within database and process mining software and the amount of performance indicators needed to be limited due to the research time scope. This selection process resulted in a small set of performance indicators that were successfully used within this thesis. This relatively long list of selection steps (design
choices) are well documented (chapter 3, Methodology), but limit the possibility to replicate the analysis findings of this research for other clinical processes.

With respect to the link between process execution and process effectiveness, process mining proved to be a useful tool for investigating the link. Statistics and evaluative meetings were however also conducted. Without these techniques, the found links could neither be given the right scientific evidence or well-understood and ‘put in the greater picture’. It’s the authors view that process mining techniques are especially useful for pointing out (performance) problems or interesting differences and that the combination of process mining with other research instruments can greatly enlarge their practical value. Furthermore, the inclusion of process owners in the research process and the inclusion of statistically sound conclusions can greatly enhance the foundation for organisational or policy change.

Based on this research, several process improvement recommendations were made to the process owners. First, the created patient groups and the differences among groups with respect to the average time between the pre-operative examination and the first surgery led to the recommendation to critically look at the current surgery planning policy. Surgical continuity interacts with timeliness. The performance on the Treeknorm can be improved, but this improvement might go at the expense of surgical continuity. Second, it was recommended to make sure that the policy on visit status changes is clear to all resources involved in the policlinic visits, especially optometrists. This can help to lower the amount of deviant visit status changes and can hereby reduce the (average) throughput time of patients in policlinic visits. Third, it was recommended to look for additional causes for the long throughput times in the policlinic visits. The deviant visit status changes are one of the causes, but after removing these from the dataset the average throughput times were still a lot larger than the benchmark times. Possible causes may lie in the planned duration of eye measurements and consultations and in the fraction of patients that are too late. Further empirical research is required.

Future thesis projects could fulfil these recommendations. One process improvement project could focus on the surgery planning policy and could bring the consequences of the current policy and the likely of effects of alterations into vision. A process mining project could focus on the visit status changes. Performing process mining on this level is quite new. In this thesis project only throughput times were taken into account, since treatment and waiting times could not be separated. Since the 1st of May 2013, additional visit status changes are captured for the investigated process. This makes it possible to separate treatment and waiting times. Process mining findings could be compared with measurements to (further) determine the value and accuracy of process mining on this level of detail. This fits the identified data problem by Mans et al. (2013) on the granularity of timestamps. Lastly, another project could specifically focus on the policlinic visits and could investigate additional causes for the long throughput times.

From a scientific point of view, it would be valuable to validate the used methodology, focusing again on the same link. The data perspective could be added as well. Furthermore, it’s the authors view that it would be practically and scientifically valuable to integrate statistics within process mining software. It would greatly aid in drawing valid conclusions, especially with respect to performance problems. Lastly, note that no new (process mining) techniques were developed to perform this thesis project, so from that perspective this thesis is not novel at all. However, the used techniques were applied in a different manner, using the developed methodology, and for a different purpose. This is novel and proved effective in this case study.
References


## Appendices

### Appendix A: General planning surgeries and postoperative examinations

<table>
<thead>
<tr>
<th>Surgeon</th>
<th>Week 0</th>
<th>Day 1</th>
<th>Week 1</th>
<th>Week 2</th>
<th>Day 15</th>
<th>Week 3</th>
<th>Week 7</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Junior doctor</strong></td>
<td>Surgery</td>
<td>Physical examination</td>
<td>Physical examination</td>
<td>Surgery</td>
<td>Physical examination</td>
<td>Physical examination</td>
<td>Physical examination</td>
</tr>
<tr>
<td><strong>Medical specialist</strong></td>
<td>Surgery</td>
<td>Consult by phone</td>
<td>Physical examination</td>
<td>Surgery</td>
<td>Consult by phone</td>
<td>Physical examination</td>
<td>Physical examination</td>
</tr>
</tbody>
</table>
Appendix B: Catquest-9SF questionnaire (in Dutch)

Geachte heer/mevrouw,

Namens de afdeling Oogheelkunde van het academisch ziekenhuis Maastricht (azM) zou ik u graag een aantal vragen willen stellen over uw huidige gezichtsvermogen. De resultaten worden gebruik om ons extra inzicht te geven in de uitkomsten van onze staarbehandelingen.

Deze vragenlijst bestaat uit twee vragen over uw algemene gezondheid en negen vragen over uw huidige gezichtsvermogen. Het invullen duurt ongeveer 5 tot 10 minuten.

Kies na elke vraag het antwoord dat het best uw situatie beschrijft. Neem zo veel tijd als u nodig hebt om elke vraag te beantwoorden.

Probeer zo goed mogelijk antwoord te geven op de vragen. Er zijn geen goede of foute antwoorden. Beantwoord alstublieft elke vraag.

Vul de vragen in zonder uw antwoorden met uw vrienden of familie te bespreken. Als u niet zeker weet hoe u een vraag moet beantwoorden, geef dan het beste antwoord dat u kunt geven en schrijf een toelichting in de kantlijn.

Alle informatie die de identificatie van iemand die deze vragenlijst invulde mogelijk zou maken, zal als strikt vertrouwelijk worden beschouwd. Zulke informatie zal alleen voor het doel van dit onderzoek worden gebruikt en zal niet zonder voorafgaande toestemming worden geopenbaard of vrijgegeven voor welk doel dan ook, behalve als dat wettelijk is vereist.

Stuurt u de vragenlijst na invullen terug met de bijgevoegde retourenvelop. Wij stellen uw medewerking erg op prijs!

Met vriendelijke groet,
Frank van den Biggelaar en Mark Overduin

Onderzoekers afdeling Oogheelkunde academisch ziekenhuis Maastricht
1. Algemene gezondheid

Dit deel van de vragenlijst bevat twee vragen over uw algemene gezondheid. U kunt het meest passende antwoord aankruisen.

_Hoe zou u uw algemene gezondheid omschrijven?_

□ Uitstekend
□ Zeer goed
□ Goed
□ Matig
□ Slecht

_Hoe heeft u op dit moment andere oogziekten of oogafwijkingen die uw gezichtsvermogen belemmeren?_

□ Ja, namelijk ……………………………………………………………………………………………………………………………
□ Nee

2. Uw huidige gezichtsvermogen

Dit deel van de vragenlijst bevat een lijst van negen activiteiten. De vraag is hoeveel moeite u heeft met deze activiteiten vanwege uw gezichtsvermogen. U kunt het best passende antwoord aankruisen. _Als u een bril of contactlenzen draagt, ga er dan bij de beantwoording van de vragen van uit dat u deze draagt._

<table>
<thead>
<tr>
<th>Activiteit</th>
<th>Heel veel moeite</th>
<th>Tamelijk veel moeite</th>
<th>Een beetje moeite</th>
<th>Geen moeite</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Het lezen van tekst in de krant</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>2. Het herkennen van gezichten van mensen</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>vragen</td>
<td>Heel veel moeite</td>
<td>Tamelijk veel moeite</td>
<td>Een beetje moeite</td>
<td>Geen moeite</td>
</tr>
<tr>
<td>--------</td>
<td>-----------------</td>
<td>----------------------</td>
<td>-------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>3. Het zien van prijzen in de winkel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Het lopen op een onregelmatige ondergrond</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Het verrichten van fijn handwerk zoals knutselen, naaien, breien of timmerwerk</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Het lezen van ondertitels op de TV</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Het uitvoeren van uw favoriete hobby</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Geeft uw huidige gezichtsvermogen u op welke manier dan ook moeilijkheden in uw dagelijks leven?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

9. Bent u tevreden of ontevreden met uw huidige gezichtsvermogen?

   Erg ontevreden  Nogal ontevreden  Behoorlijk tevreden  Erg tevreden

**Dit waren de vragen die wij u wilden stellen. Wij danken u hartelijk voor uw medewerking!**
Appendix C: Pre-analysis questionnaire (in Dutch)

Goedemorgen meneer/mevrouw,

Ik ben Mark Overduin en ik wil u voor mijn afstudeeronderzoek in samenwerking met het azM graag een aantal vragen stellen over uw tevredenheid over de ontvangen zorg. Deze vragenlijst bestaat uit twee onderdelen die op zichzelf staan. De resultaten worden gebruikt om meer inzicht te krijgen in de prestaties van onze polikliniek en om waar mogelijk de dienstverlening te verbeteren. Verder wordt uw informatie uiteraard ten allen tijde vertrouwelijk behandeld.

1. Uw tevredenheid over de ontvangen zorg

Onderstaande vragen gaan over uw ervaring met de oogarts en het ziekenhuis waar u uw staaroperatie heeft ondergaan. Als u met meer dan één oogarts te maken heeft gehad, kies dan de oogarts met wie u het meest te maken heeft gehad.

Deze serie vragen wordt ingeleid met een voorbeeld en enkele aanwijzingen. Leest u alstublieft het voorbeeld en de aanwijzingen goed door. Hoewel sommige vragen op elkaar lijken, is het voor het onderzoek erg belangrijk dat u de vragen zo volledig mogelijk invult en geen vragen overslaat. Er zijn geen goede of foute antwoorden; het gaat om uw mening en uw ervaringen.

<table>
<thead>
<tr>
<th>Voorbeeld</th>
<th>Nee</th>
<th>Eigenlijk niet</th>
<th>Eigenlijk wel</th>
<th>Ja</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>De oogarts die mij behandelt...</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>staat mij altijd vriendelijk te woord</td>
<td>☐</td>
<td>✗</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

In dit voorbeeld heeft u de tweede mogelijkheid aangekruist. Dit betekent dat u er even over moet nadenken, maar dat u eigenlijk niet vindt dat uw oogarts u altijd vriendelijk te woord staat.

Hieronder staat een aantal zinnen, die allemaal beginnen met ‘De oogarts die mij behandelt ...’. Wij vragen u achter iedere zin aan te geven hoe belangrijk u hetgeen vindt, dat hierin wordt genoemd.
### De oogarts die mij behandelt...

<table>
<thead>
<tr>
<th></th>
<th>Nee</th>
<th>Eigenlijk niet</th>
<th>Eigenlijk wel</th>
<th>Ja</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. laat mij meebeslissen over de behandeling of de hulp die ik krijg</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. neemt mij altijd serieus</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. komt gemaakte afspraken altijd stipt na</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. laat mij langer dan 15 minuten in de wachtkamer wachten</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. geeft altijd, in voor mij begrijpelijke taal, uitleg over medicijnen (o.a. oogdruppels) die worden voorgeschreven</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. schrijft altijd medicijnen voor die volledig door het ziekenfonds of mijn verzekering worden vergoed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. is telefonisch altijd goed bereikbaar</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. zorgt er voor dat ik na een verwijzing snel (binnen 2 weken) bij hem/haar terecht kan</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. stemt de zorg, die ik krijg, altijd af op de zorg van andere hulpverleners</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. is goed op de hoogte van mijn gezondheidsstoestand</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. spreekt met mij af wat ik moet doen in geval van nood</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. heeft een wacht- en praktijkruimte die goed toegankelijk is voor rolstoelgebruikers of mensen die slecht ter been zijn</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13. vertelt mij altijd wat de risico’s zijn van een behandeling</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14. heeft altijd voldoende tijd voor mij</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15. is altijd bereid met mij te praten over zaken die naar mijn mening niet goed zijn verlopen</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
In de vorige vragen van dit deel van de vragenlijst ging het om zaken waarmee alle patiënten te maken kunnen krijgen. Wij zijn echter ook benieuwd naar uw oordeel over zaken die specifiek te maken hebben met uw staaroperatie. Wilt u ook hier weer uw gekozen optie aankruisen?

<table>
<thead>
<tr>
<th>De oogarts die mij behandelt...</th>
<th>Nee</th>
<th>Eigenlijk niet</th>
<th>Eigenlijk wel</th>
<th>Ja</th>
</tr>
</thead>
<tbody>
<tr>
<td>16. geeft mij duidelijke informatie over wat ik wel en niet mag doen na een staaroperatie</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>17. informeert mij één week van tevoren, via een brief, schriftelijk over de dag en het tijdstip van mijn staaroperatie</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>18. informeert mij tussentijds hoe lang het nog duurt voordat ik word geopereerd</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>19. verstrekt mij een informatiefolder waarin precies staat beschreven wat een staaroperatie inhoudt</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>20. vertelt mij, tijdens de staaroperatie zelf, precies wat er gebeurt</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>21. doet altijd kalm en rustig zijn/haar werk</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>22. houdt altijd rekening met mijn specifieke wensen</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>23. is altijd vriendelijk</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>24. gaat altijd serieus in op al mijn vragen, die te maken hebben met mijn staaroperatie</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>25. is altijd dezelfde persoon</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>26. zorgt er voor dat de wachttijd voor mijn (eerste) staaroperatie niet meer dan twee maanden bedraagt</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>
De oogarts die mij behandelt...

<table>
<thead>
<tr>
<th></th>
<th>Nee</th>
<th>Eigenlijk niet</th>
<th>Eigenlijk wel</th>
<th>Ja</th>
</tr>
</thead>
<tbody>
<tr>
<td>27.</td>
<td>regelt het zo dat alle voorbereidende onderzoeken voor mijn staaroperatie op één dag plaatsvinden</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>28.</td>
<td>beschikt over een balie met voldoende privacy</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>29.</td>
<td>beschikt over een afdeling met voldoende mogelijkheden om iets te eten of te drinken</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>30.</td>
<td>zorgt ervoor dat de informatie van verschillende artsen (of andere hulpverleners) goed op elkaar is afgestemd</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>31.</td>
<td>biedt mij de mogelijkheid om, als daar aanleiding toe is met voorrang te worden geopereerd</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

Dit waren de vragen die wij u wilden stellen. Wij danken u hartelijk voor uw medewerking!
Appendix D: Descriptive statistics pre-analysis

<table>
<thead>
<tr>
<th>Sample statistic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample size</td>
<td>40</td>
</tr>
<tr>
<td>Age average</td>
<td>71</td>
</tr>
<tr>
<td>Age spread</td>
<td>49 (min) – 86 (max)</td>
</tr>
<tr>
<td>Health-status average (1 = very bad to 4 = very good)</td>
<td>2.9</td>
</tr>
<tr>
<td>Health-status spread</td>
<td>1 (min) – 4 (max)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Item</th>
<th>Average</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quote-1</td>
<td>3.51</td>
<td>0.79</td>
</tr>
<tr>
<td>Quote-2</td>
<td>3.85</td>
<td>0.43</td>
</tr>
<tr>
<td>Quote-3</td>
<td>3.64</td>
<td>0.63</td>
</tr>
<tr>
<td>Quote-4</td>
<td>2.76</td>
<td>1.17</td>
</tr>
<tr>
<td>Quote-5</td>
<td>3.48</td>
<td>0.93</td>
</tr>
<tr>
<td>Quote-6</td>
<td>3.27</td>
<td>1.07</td>
</tr>
<tr>
<td>Quote-7</td>
<td>3.58</td>
<td>0.79</td>
</tr>
<tr>
<td>Quote-8</td>
<td>3.50</td>
<td>0.85</td>
</tr>
<tr>
<td>Quote-9</td>
<td>3.32</td>
<td>0.83</td>
</tr>
<tr>
<td>Quote-10</td>
<td>3.36</td>
<td>1.02</td>
</tr>
<tr>
<td>Quote-11</td>
<td>3.67</td>
<td>0.76</td>
</tr>
<tr>
<td>Quote-12</td>
<td>3.76</td>
<td>0.65</td>
</tr>
<tr>
<td>Quote-13</td>
<td>3.64</td>
<td>0.78</td>
</tr>
<tr>
<td>Quote-14</td>
<td>3.63</td>
<td>0.63</td>
</tr>
<tr>
<td>Quote-15</td>
<td>3.72</td>
<td>0.46</td>
</tr>
<tr>
<td>Quote-16</td>
<td>3.79</td>
<td>0.58</td>
</tr>
<tr>
<td>Quote-17</td>
<td>3.85</td>
<td>0.49</td>
</tr>
<tr>
<td>Quote-18</td>
<td>2.86</td>
<td>1.31</td>
</tr>
<tr>
<td>Quote-19</td>
<td>3.92</td>
<td>0.48</td>
</tr>
<tr>
<td>Quote-20</td>
<td>3.56</td>
<td>0.91</td>
</tr>
<tr>
<td>Quote-21</td>
<td>3.92</td>
<td>0.27</td>
</tr>
<tr>
<td>Quote-22</td>
<td>3.62</td>
<td>0.64</td>
</tr>
<tr>
<td>Quote-23</td>
<td>3.85</td>
<td>0.37</td>
</tr>
<tr>
<td>Quote-24</td>
<td>3.95</td>
<td>0.22</td>
</tr>
<tr>
<td>Quote-25</td>
<td>2.31</td>
<td>1.32</td>
</tr>
<tr>
<td>Quote-26</td>
<td>3.66</td>
<td>0.88</td>
</tr>
<tr>
<td>Quote-27</td>
<td>3.82</td>
<td>0.56</td>
</tr>
<tr>
<td>Quote-28</td>
<td>3.44</td>
<td>0.91</td>
</tr>
<tr>
<td>Quote-29</td>
<td>3.53</td>
<td>0.73</td>
</tr>
<tr>
<td>Quote-30</td>
<td>3.69</td>
<td>0.58</td>
</tr>
<tr>
<td>Quote-31</td>
<td>3.60</td>
<td>0.56</td>
</tr>
</tbody>
</table>
Appendix E: Demand orientation analysis selection steps in Microsoft Access

The following steps were carried out to prepare the event log:

1. Patients were selected that had as traject diagnosis ‘Cataract’ and that had their final postoperative examination between 1-10-2012 and 22-04-2013. This gave 616 records. Sometimes there were multiple final postoperative examination registrations per patient. Further investigation revealed that primary reason for this was human registration error, e.g. a non-final physical examination was registered as a final physical examination.

2. For patients in step 1 a selection was made on the service ‘OK_ANKER’ (same time period restriction). This dummy service should be recorded for each surgery, since all OK events are tied to this dummy service. Furthermore, the OK event ‘AANKOK’ (entering the surgery room) should be present. This query returned 699 records. Of these 699 surgeries a part can be contributed to patients that only had one surgery and another part to patients that had two surgeries.

3. For the registered cataract surgeries in step 2 a selection was made on patients that have 2 surgery registrations. This returned 185 records (patients). Furthermore, it was checked whether there were also patients where more than two surgeries were registered. This was not the case.

4. For the 185 patients found in step 3, the corresponding health cases were taken. This gave 394 records. Here 370 records were expected (2 records for each patient). Further investigation revealed that the primary reason for difference was that sporadically the second surgery was registered at both the health case belonging to the first surgery (and corresponding health services) and the health case belonging to the second surgery (and corresponding health services).

5. All the services belonging to the second health case were separated from the services belonging to the first health case and marked (a ‘1’ was added).

6. The final postoperative examinations were added from the appointments table. This was done since services were only sporadically registered at the physical examination date (for only 49 out of 185 patients a service registered was at the date of the physical examination). This resulted in 185 distinct records (registered final physical examinations for the 185 patients from the previous steps).

7. The services belonging to the first health case, second health case and the appointments for the final postoperative examination were integrated. The final query resulted in 2396 records (services registered and final postoperative examination appointments).
Appendix F: Demand orientation analysis Microsoft Access queries

Continuïteit_hulp1

SELECT DISTINCT alleTrajecten.Patiënt, afspraakreserveringen.[Omschrijving lang], afspraakreserveringen.[Planntype bezoekpl], afspraakreserveringen.Stornoteken, alleTrajecten.Diagnose
FROM alleTrajecten INNER JOIN afspraakreserveringen ON alleTrajecten.Patiënt = afspraakreserveringen.Patiënt
WHERE (((afspraakreserveringen.[Planntype bezoekpl])="EC") AND ((afspraakreserveringen.Stornoteken)<>'X') AND ((alleTrajecten.Diagnose)="Cataract") AND ((afspraakreserveringen.Begindatum)>=#10/1/2012# And (afspraakreserveringen.Begindatum)<=#4/22/2013#));

Continuïteit_hulp2

SELECT DISTINCT Continuïteit_hulp1.Patiënt, verrichtingenMetTekst.Verrichting, verrichtingenMetTekst.[Verrichttekst 1], verrichtingenMetTekst.[Begindatum Verr], ok_tijden.Stornoteken, ok_tijden.[ID Tijdstip]
FROM (Continuïteit_hulp1 INNER JOIN verrichtingenMetTekst ON Continuïteit_hulp1.Patiënt = verrichtingenMetTekst.Patiënt) INNER JOIN ok_tijden ON verrichtingenMetTekst.[Volgnr verrichting] = ok_tijden.[Volgnr verrichting]
WHERE (((verrichtingenMetTekst.Verrichting)="OK_ANKER") AND ((verrichtingenMetTekst.[Begindatum Verr])>=#10/1/2012# And (verrichtingenMetTekst.[Begindatum Verr])<=#4/22/2013#) AND ((ok_tijden.Stornoteken)<>'X') AND ((ok_tijden.[ID Tijdstip])="AANKOK");

Continuïteit_hulp3

SELECT DISTINCT Continuïteit_hulp2.Patiënt, Count([Continuïteit_hulp2.Begindatum Verr]) AS AantalVanDatum
FROM Continuïteit_hulp2
GROUP BY Continuïteit_hulp2.Patiënt
HAVING (((Count([Continuïteit_hulp2.Begindatum Verr]))=2));

Continuïteit_hulp4

**Continuïteit_hulp5**

SELECT Continuïteit_hulp4.Patiënt, Min(Continuïteit_hulp4.[Begindatum Verr]) AS [MinVanBegindatum Verr]
FROM Continuïteit_hulp4
GROUP BY Continuïteit_hulp4.Patiënt;

**Continuïteit_hulp6**

SELECT Continuïteit_hulp4.Patiënt, Min(Continuïteit_hulp4.Ziektegeval) AS MinVanZiektegeval
FROM Continuïteit_hulp5 INNER JOIN Continuïteit_hulp4 ON (Continuïteit_hulp5.[MinVanBegindatum Verr] = Continuïteit_hulp4.[Begindatum Verr]) AND (Continuïteit_hulp5.Patiënt = Continuïteit_hulp4.Patiënt)
GROUP BY Continuïteit_hulp4.Patiënt;

**Continuïteit_hulp7**

WHERE (([verrichtingenMetTekst].[Verrichttekst 1])<>"dagverpleging zwaar") AND ([verrichtingenMetTekst].[Begindatum Verr])>=#10/1/2012# And ([verrichtingenMetTekst].[Begindatum Verr])<=#4/22/2013#) AND ([verrichtingenMetTekst].[Gestorneerd door]="")
ORDER BY Continuïteit_hulp6.Patiënt, verrichtingenMetTekst.[Begindatum Verr], [verrichtingenMetTekst].[Begindatum Verr] & " " & [Begintijd];

**Continuïteit_hulp8**

SELECT DISTINCT [Continuïteit_hulp4].Patiënt, Max([Continuïteit_hulp4].[Begindatum Verr]) AS [MaxVanBegindatum Verr]
FROM Continuïteit_hulp4
GROUP BY [Continuïteit_hulp4].Patiënt;

**Continuïteit_hulp9**

SELECT Continuïteit_hulp4.Patiënt, Min(Continuïteit_hulp4.Ziektegeval) AS MinVanZiektegeval
FROM Continuïteit_hulp4 INNER JOIN Continuïteit_hulp8 ON (Continuïteit_hulp4.[Begindatum Verr] = Continuïteit_hulp8.[MaxVanBegindatum Verr]) AND (Continuïteit_hulp4.Patiënt = Continuïteit_hulp8.Patiënt)
GROUP BY Continuïteit_hulp4.Patiënt;
**Continuiteit_hulp10**


**Continuiteit_hulp11**

SELECT Continuiteit_hulp10.Patiënt, Min(Continuiteit_hulp10.Timestamp) AS MinVanTimestamp FROM Continuiteit_hulp10 GROUP BY Continuiteit_hulp10.Patiënt;

**Continuiteit_hulp12**


**Continuiteit_hulp13**


**Continuiteit_hulp14**

**Continuiteit_hulp15**

SELECT Continuiteit_hulp14.Patiënt, [MaxVanBegindatum] & " " & "00:00:00" AS [Timestamp]
FROM Continuiteit_hulp14;

**Continuiteit_hulp16**

SELECT * from [Continuiteit_hulp7]
UNION select * from [Continuiteit_hulp12]
UNION select [Patiënt], [Timestamp], "Eindcontrole" As [Verrichting], Null As [Uitvoerend Arts],
Null As [Functie] from [Continuiteit_hulp15];

**Continuiteit_final**

SELECT DISTINCT Continuiteit_hulp16.Patiënt, Continuiteit_hulp16.Timestamp,
Continuiteit_hulp16.Verrichting, Continuiteit_hulp16.[Uitvoerend Arts],
Continuiteit_hulp16.Functie
FROM Continuiteit_hulp16 LEFT JOIN patient ON Continuiteit_hulp16.Patiënt = patient.Patiënt;
Appendix G: High-level timeliness analysis selection steps in Microsoft Access

1. Patients were selected that had as tracjotent diagnosis ‘Cataract’ and that had their final physical examination between 1-10-2012 and 22-04-2013. This resulted in 616 records.

2. For patients in step 1 a selected was made on the service ‘OK_ANKER’ (same time period restriction). This dummy service should be recorded for each surgery, since all OK events are tied to this dummy service. Furthermore, the OK_event ‘AANKOK’(entering the surgery room) should be registered. This query returned 699 records.

3. For the 699 surgeries found in step 2, the corresponding health cases were taken. For these health cases all case movements were extracted from the Case movements table that were performed between 1-10-2012 and 22-04-2013. This query returned 3114 records (distinct registered case movements).

4. For the registered case movements, the corresponding amount of distinct patients was determined. This query returned 514 records (patients).

5. Using several help-queries it was determined that 2294 case movements correspond to the first registered health case of patients that had two surgeries or to patients that had only one surgery (same time period restrictions). 842 case movements were registered for the second registered health case of patients that had two surgeries (same time period restrictions). The sum of these case movements (3136 records) is somewhat larger than the amount of case movements found in step 3. This difference can be explained by the fact that sometimes case movements are registered at two (instead of one) health case, as also identified for services performed during the log preparation for the demand orientation analysis (see subsection 4.1.1).

6. Lastly, using several help-queries the case movements corresponding to the pre-operative examination and the final examination were enriched with information from respectively the Services performed and the Appointments table to be able to distinguish these visits from the other visits. This was considered important since these case movements are important process milestones and correspond to boundaries of the process splits created in the demand orientation analysis. Note that this limited the amount of case movements included in the analysis for these two visits, since now for these two visits only visits for which a service or an appointment was recorded were included. The surgeries (the other process split boundaries) were already distinguishable. The final query consisted of 3136 records (case movements).
Appendix H: High-level timeliness analysis Microsoft Access queries

**Tijdigheid_hoog_hulp1**


**Tijdigheid_hoog_hulp2**


**Tijdigheid_hoog_hulp3**


**Tijdigheid_hoog_hulp4**

**Tijdigheid_hoog_hulp5**

FROM Tijdigheid_hoog_hulp4 INNER JOIN Tijdigheid_hoog_hulp3
(Tijdigheid_hoog_hulp4.Patiënt = Tijdigheid_hoog_hulp3.Patiënt);

**Tijdigheid_hoog_hulp6**

SELECT DISTINCT Tijdigheid_hoog_hulp3.Patiënt, Tijdigheid_hoog_hulp3.Ziektegeval,
Tijdigheid_hoog_hulp3.omschrijving AS [Type beweging], Tijdigheid_hoog_hulp3.Begindatum
FROM Tijdigheid_hoog_hulp5 INNER JOIN Tijdigheid_hoog_hulp3
ON (Tijdigheid_hoog_hulp5.Ziektegeval = Tijdigheid_hoog_hulp3.Ziektegeval) AND
(Tijdigheid_hoog_hulp5.Patiënt = Tijdigheid_hoog_hulp3.Patiënt)
WHERE (((Tijdigheid_hoog_hulp3.Begindatum)>=#1/10/2012# And
(Tijdigheid_hoog_hulp3.Begindatum)<=#4/22/2013#));

**Tijdigheid_hoog_hulp7**

SELECT Tijdigheid_hoog_hulp2.Patiën, Count(Tijdigheid_hoog_hulp2.Datum) AS AantalVanDatum
FROM Tijdigheid_hoog_hulp2
GROUP BY Tijdigheid_hoog_hulp2.Patiën
HAVING (((Count(Tijdigheid_hoog_hulp2.Datum))>=2));

**Tijdigheid_hoog_hulp8**

FROM Tijdigheid_hoog_hulp7 INNER JOIN Tijdigheid_hoog_hulp3
ON Tijdigheid_hoog_hulp7.Patiën = Tijdigheid_hoog_hulp3.Patiën
GROUP BY Tijdigheid_hoog_hulp3.Patiën;

**Tijdigheid_hoog_hulp9**

FROM Tijdigheid_hoog_hulp3 INNER JOIN Tijdigheid_hoog_hulp8
ON (Tijdigheid_hoog_hulp3.Begindatum = Tijdigheid_hoog_hulp8.MaxVanBegindatum) AND
(Tijdigheid_hoog_hulp3.Patiën = Tijdigheid_hoog_hulp8.Patiën);
**Tijdigheid_hoog_hulp10**


**Tijdigheid_hoog_hulp11**

SELECT * From [Tijdigheid_hoog_hulp6] UNION select * From [Tijdigheid_hoog_hulp10];

**Tijdigheid_hoog_hulp12**


**Tijdigheid_hoog_hulp13**


**Tijdigheid_hoog_hulp14**

Tijdigheid_hoog_final

WHERE (((Tijdigheid_hoog_hulp13.Begindatum) =>'#1/10/2012#'))
Appendix I: Low-level timeliness analysis selection steps in Microsoft Access

The event-log created in the high-level waiting time analysis was taken as a starting point. This event log contained (amongst others) all pre-operative examination visits and the final examination visits that occurred between 1-10-2012 and 22-04-2013.

1. To create the event-log for the pre-operative examination visits (Event-log 1), the event-log of the high-level waiting time analysis was restricted to only pre-operative examination visits and coupled to the SAP change-log tables that contained information about visit status changes. The SAP change logs only contained information about visits between 1-10-2012 and 22-02-2013 (the SAP back-up date). In total 592 visit status changes were included in the event-log. Additionally, the planned start times of the visits were added for the pre-operative examination visits in question (171 planned start times). In total the event-log consisted of 763 events.

2. To create the event-log for the final examination visits (Event-log 2), the same approach as described in step 2 was followed. Now the event-log of the high-level waiting time analysis was restricted to only final postoperative examination visits. In total 1014 visit status changes were included in the event-log. Additionally, the planned start times of the visits were added for the pre-operative examination visits in question (298 planned start times). In total the event-log consisted of 1312 events.
Appendix J: Low-level timeliness analysis Microsoft Access queries

**Tijdigheid_laag_hulp1**

FROM (Bezoekstatussen_legenda AS Bezoekstatussen_legenda_1 INNER JOIN (Bezoekstatussen_legenda INNER JOIN (CDPOS_bezoekstatussen INNER JOIN CDHDR_bezoekstatussen ON (CDPOS_bezoekstatussen.Documentnr=CDHDR_bezoekstatussen.Documentnr) AND (CDPOS_bezoekstatussen.Objectwaarde=CDHDR_bezoekstatussen.Objectwaarde))) ON Bezoekstatussen_legenda.Waarde=CDPOS_bezoekstatussen.[Oude wrd]) INNER JOIN NBEW_bezoekstatussen ON CDHDR_bezoekstatussen.Objectwaarde=NBEW_bezoekstatussen.[Objectwaarde in CDPOS/CDHDR]
ORDER BY CDHDR_bezoekstatussen.Objectwaarde, CDHDR_bezoekstatussen.Datum, CDHDR_bezoekstatussen.Tijdstip;

**Tijdigheid_laag_hulp2_EC**

FROM [Tijdigheid analyse (hoog niveau)] INNER JOIN Tijdigheid_laag_hulp1 ON ([Tijdigheid analyse (hoog niveau)].Ziektegeval=[Tijdigheid_laag_hulp1].ZGV) AND ([Tijdigheid analyse (hoog niveau)].Begindatum=[Tijdigheid_laag_hulp1].Datum)
WHERE ((([Tijdigheid analyse (hoog niveau)].Event)="Bezoek 1 EC" Or ([Tijdigheid analyse (hoog niveau)].Event)="Bezoek EC"))
ORDER BY [Tijdigheid analyse (hoog niveau)].Patiënt, [Tijdigheid_laag_hulp1].Tijdstip;

**Tijdigheid_laag_hulp3_EC**

SELECT DISTINCT Tijdigheid_laag_hulp2_EC.Patiënt, afspraakreserveringen.[Begintijd beweging] AS Tijdstip, Tijdigheid_laag_hulp2_EC.Datum
FROM Tijdigheid_laag_hulp2_EC INNER JOIN afspraakreserveringen ON (Tijdigheid_laag_hulp2_EC.Patiënt = afspraakreserveringen.Patiënt) AND (Tijdigheid_laag_hulp2_EC.Datum = afspraakreserveringen.Begindatum);

**Tijdigheid_laag_final_EC**

SELECT * from [Tijdigheid_laag_hulp2_EC]
UNION select [Patiënt], "Geplande begintijd" As [Statusverandering], [Tijdstip], [Datum] from [Tijdigheid_laag_hulp3_EC]
**Tijdigheid_laag_hulp2_Pre-Op**

```
FROM [Tijdigheid analyse (hoog niveau)] INNER JOIN Tijdigheid_laag_hulp1 ON ([Tijdigheid analyse (hoog niveau)].Ziektegeval = Tijdigheid_laag_hulp1.ZGV) AND ([Tijdigheid analyse (hoog niveau)].Begindaag = Tijdigheid_laag_hulp1.Datum)
WHERE ((([Tijdigheid analyse (hoog niveau)].Event)='Bezoek oog-IOL-master'))
ORDER BY [Tijdigheid analyse (hoog niveau)].Patiënt, Tijdigheid_laag_hulp1.Tijdstip;
```

**Tijdigheid_laag_hulp3_Pre-Op**

```
FROM [Tijdigheid_laag_hulp2_Pre-Op] INNER JOIN afspraakreserveringen ON ([Tijdigheid_laag_hulp2_Pre-Op].Datum = afspraakreserveringen.Begindatum) AND ([Tijdigheid_laag_hulp2_Pre-Op].Patiënt = afspraakreserveringen.Patiënt);
```

**Tijdigheid_laag_final_Pre-Op**

```
SELECT * from [Tijdigheid_laag_hulp2_Pre-Op]
UNION select [Patiënt], "Geplande begintijd" As [Statusverandering], [Tijdstip], [Datum] from [Tijdigheid_laag_hulp3_Pre-Op];
```
Appendix K: Clinical effectiveness analysis selection steps in Microsoft Access

1. Patients were selected that had as tracer diagnosis ‘Cataract’ and that had their final physical examination between 1-10-2012 and 22-04-2013. This gave 615 records.
2. For patients in step 1 a selection was made on the service ‘OK_ANKER’ (same time period restriction). This dummy service should be recorded for each surgery, since all OK events are tied to this dummy service. Furthermore, the OK event ‘AANKOK’ (entering the surgery room) should be registered. This query returned 699 records.
3. For the registered cataract surgeries in step 2 a selection was made on patients that have exactly one surgery registration. This returned 329 records (patients and corresponding health cases).
4. A selection was made on the services performed for these patients within the found health cases. This query returned 2675 records (services performed).
5. The final postoperative examinations were added for these patients from the appointments table. This was done since services were only sporadically registered at the final postoperative examination date. This resulted in an extra 311 records (appointments).
6. A dataset containing all services performed for (on) patients with one surgery (containing 2675 + 311 = 2986 records) was subsequently joined with the already created dataset for the demand orientation analysis (2396 records). The last dataset contained all services performed for patients that had two surgeries. The combined dataset contained 5382 records (2675 + 311+ 2396 record).
7. The surgery service ‘Dagverpleging-zwaar’ was respectively marked with ‘HOOG’ for high-volume group (as determined in Disco) and marked with ‘LAAG’ for the low-volume group and added to the dataset created in step 6. The final query returned 6063 records (events)
Appendix L: Clinical effectiveness analysis Microsoft Access queries

**Klinische_effectiviteit_hulp1**

```sql
SELECT DISTINCT alleTrajecten.Patiënt, afspraakreserveringen.Begindatum
FROM alleTrajecten INNER JOIN afspraakreserveringen ON alleTrajecten.Patiënt = afspraakreserveringen.Patiënt
WHERE (((afspraakreserveringen.Begindatum) >= #10/1/2012# And (afspraakreserveringen.Begindatum) <= #4/22/2013#) AND ((afspraakreserveringen.[Planntype bezoekpl]) = "EC") AND ((afspraakreserveringen.Stornoteken) <> 'X') AND ((alleTrajecten.Diagnose) = "Cataract");
```

**Klinische_effectiviteit_hulp2**

```sql
SELECT DISTINCT Klinische_effectiviteit_hulp1.Patiënt, verrichtingenMetTekst.Verrichting,
ok_tijden.Datum
FROM Klinische_effectiviteit_hulp1 INNER JOIN (verrichtingenMetTekst INNER JOIN ok_tijden ON verrichtingenMetTekst.[Volgnr verrichting] = ok_tijden.[Volgnr verrichting]) ON Klinische_effectiviteit_hulp1.Patiënt = verrichtingenMetTekst.Patiënt
WHERE (((verrichtingenMetTekst.Verrichting) = "OK_ANKER") AND ((ok_tijden.Datum) >= #10/1/2012# And (ok_tijden.Datum) <= #4/22/2013#) AND ((ok_tijden.[ID Tijdstip]) = "AANKOK") AND ((ok_tijden.Stornoteken) <> 'X'));
```

**Klinische_effectiviteit_hulp3**

```sql
SELECT DISTINCT [Klinische_effectiviteit_hulp2].Patiënt,
Count([Klinische_effectiviteit_hulp2].Datum) AS AantalVanDatum
FROM Klinische_effectiviteit_hulp2
GROUP BY [Klinische_effectiviteit_hulp2].Patiënt
HAVING (((Count([Klinische_effectiviteit_hulp2].Datum)) = 1));
```

**Klinische_effectiviteit_hulp4**

```sql
SELECT DISTINCT distinctZgv.Patiënt, Min(distinctZgv.Ziektegeval) AS Ziektegeval
GROUP BY distinctZgv.Patiënt, verrichtingenMetTekst.Verrichting, verrichtingenMetTekst.[Verrichttekst 1]
HAVING (((verrichtingenMetTekst.Verrichting) = "OK_ANKER") AND ((verrichtingenMetTekst.[Verrichttekst 1]) = "OK Anker verrichtingen");
```
**Klinische_effectiviteit_hulp5**


**Klinische_effectiviteit_hulp6**


**Klinische_effectiviteit_hulp7**

SELECT * from [Continuiteit_final] UNION select * from [Klinische_effectiviteit_hulp5] UNION select [Patiënt], [Timestamp], "Eindcontrole" As [Verrichting], Null As [Uitvoerend Arts], Null As [Functie] from [Klinische_effectiviteit_hulp6];

**Klinische_effectiviteit_hulp8**

SELECT [Klinische effectiviteit (volume)].Patiënt, [Klinische effectiviteit (volume)].Timestamp, [Verrichting] & " " & 'HOOG' AS Verrichting2, [Klinische effectiviteit (volume)].[Uitvoerend Arts], [Klinische effectiviteit (volume)].Functie FROM [Klinische effectiviteit (volume)] WHERE ((([Verrichting] & " " & 'HOOG') Like "*Dagverpl*"") AND (([Klinische effectiviteit (volume)].[Uitvoerend Arts])='VAHuTqJ/8bPHzt9uhps4OQ==' Or ([Klinische effectiviteit (volume)].[Uitvoerend Arts])='Mh8qOsa2RFuB60LF120XDQ=='));
**Klinische_effectiviteit_hulp9**

SELECT [Klinische effectiviteit (volume)].Patiënt, [Klinische effectiviteit (volume)].Timestamp, [Verrichting] & " " & 'LAAG' AS Verrichting2, [Klinische effectiviteit (volume)].[Uitvoerend Arts], [Klinische effectiviteit (volume)].Functie FROM [Klinische effectiviteit (volume)]
WHERE ((([Verrichting] & " " & 'LAAG') Like "**Dagverpleging**") AND (((Klinische effectiviteit (volume)).[Uitvoerend Arts]) Not In ('VAHuTqi/8bPHzt9uhps4Q==','Mh8qOsa2RFu86OLF120XDQ==')));

**Klinische_effectiviteit_final**

SELECT * from [Klinische_effectiviteit_hulp7]
UNION select [Patiënt], [Timestamp], [Verrichting2] As [Verrichting], [Uitvoerend Arts], [Functie]
from [Klinische_effectiviteit_hulp8]
UNION select [Patiënt], [Timestamp], [Verrichting2] As [Verrichting], [Uitvoerend Arts],[Functie]
from [Klinische_effectiviteit_hulp9];
Appendix M: Boxplot outlier removal throughput time clinical effectiveness analysis
Appendix N: Graphical overview time to surgery for created patient groups

62% of all patients

62% of all patients

38% of all patients

Function of surgeon
Medical specialist (88%)
Junior doctor (12%)

Medical specialist (61%)
Junior doctor (39%)