MASTER THESIS

INDUSTRIAL ENGINEERING AND MANAGEMENT

A CASE-TYPE FORECASTING AND SCHEDULING STRATEGY FOR THE OPHTHALMOLOGY OUTPATIENT CLINIC AT THE HAGAZIEKENHUIS

REDUCING VARIABILITY BETWEEN THE PLANNED DURATION AND ACTUAL DURATION TO REDUCE PERCEIVED WORKLOAD BY OPHTHALMOLOGISTS

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SUMMARY

Motivation

During the past 5 years, the production of the ophthalmology clinic of the HagaZiekenhuis in Den Haag decreased, as the clinic shifted the focus from all-encompassing care to specialistic care. While historic data shows that the number of appointments decreases, the workload experience of the ophthalmologists increases.

For this research we constructed a problem cluster with a cause-effect structure, to determine the most relevant cause for the increased workload experience. This problem cluster consists of problems that presented themselves while observing the clinic and performing data analysis on appointment data from 2017 to 2022.

From the problem cluster, we defined the core problem for the increased workload experience as:

There is high variability between the planned duration of appointments and the actual duration of the appointments.

Current situation

In the current situation of the ophthalmology clinic, the duration of an appointment is normally distributed with a mean of 9,26 minutes and a standard deviation of 4,3 minutes, while all appointments are planned for 10 minutes. Therefore, 37% of all appointments take more time than originally planned, while the other 63% take less time. Additionally, the error of the appointment duration is relatively high. This means, that the difference between running and standing still is particularly high for ophthalmologists. This is a great contributor to a high workload experience.

Approach

From the literature written about variability reduction in health care processes, we learn that the smallest variance first strategy reduced the running and standing still throughout the day. We also find examples of predicting the duration of different appointments using case types and historic data.

These three main findings from the literature help us construct a forecasting and testing approach. To make the approach easier to use and update, we build a Monte Carlo simulation. In this model, we calculate the KPIs for variability reduction that contributes to the reduction of workload experience. Several experiments are conducted in this model, based on the literature findings, predicting duration and the smallest variance first rule.

Results

A segregated planning strategy between sub agendas with a high average duration and low average duration results in the best KPI scores. However, the experiment where we apply the same strategy (prediction of appointment duration with appointment times rounded to 5 minutes, and the smallest variance first rule) to both Sub Agenda name case types gain the most. Here, the break time (with a target duration of 2 hours and 40 minutes) increases from 2 hours and 15 minutes to 2 hours and 31 minutes.

Recommendations

We recommend the ophthalmology clinic of the HagaZiekenhuis to determine a case type for every appointment, and plan the duration of the appointment to the mean duration of their case type. Additionally we suggest to apply the smallest variance first strategy in the sequence of appointments throughout the day.

To implement the case types and their duration distributions, we advise the clinic to focus first on the sub-agenda names as the primary case type and use its corresponding duration distribution. Yearly, the input data for the determination of distributions can be updated and revised. This is especially important during the upcoming years, since the impact of COVID-19 during 2020 and 2021 is unknown (and this is a big part of the input data in this research).

Discussion

From this research, we propose a scheduling strategy that narrows the difference between running and standing still of an ophthalmologist throughout the day. Using a better prediction of the actual duration of an appointment and using the smallest variance first rule in the schedule will lower the workload experience. This research shows that indeed the smallest variance first strategy can make an extra impact on variability reduction.

1. INTRODUCTION

This report describes research into the experience of an increase in workload at the ophthalmology outpatient clinic at HagaZiekenhuis. In the continuation of this report, the outpatient clinic will also be referred to as the clinic. Besides the experience of an increase in workload by the ophthalmologists, the production numbers of the clinic overall decreased. Presumably, an increase in the level of care due to patients that are more complex and more laborious causes the experience of an increase in workload. To deliver the same patient care with less workload, the clinic wants to know the reasons for this increased workload experience and wants to know how they can optimize the planning and logistics of the health care processes at the clinic.

This first chapter motivates this research. First, Section 1.1 describes the context of this research. Section 1.2 continues with the core problem. Section 1.3 describes the goal of this research as well as the scope. Last, Section 1.4 lists the research questions that are answered in the continuation of this report.

Appendix A lists the terminology and abbreviations that are used in this report.

1.1 CONTEXT

HagaZiekenhuis is a hospital located in The Hague. The name was first introduced in 2004 when three hospitals in this city merged into one. Currently, the hospital has 3500 employees and 24 specialisms[1]. On the online platform 'Zorgkaart Nederland', an initiative of 'Patiëntenfederatie Nederland', HagaZiekenhuis is rated by patients with an average of 8.1 on a scale of 10, as the second highest-rated hospital in The Hague[2]. The main core values of the HagaZiekenhuis are care, innovation, and collaboration. With their focus on these three themes, they try to achieve their mission statement:

"We will do our utmost to ensure the best possible recovery of the patient and the preservation, improvement or acceptance of the quality of life through excellent medical treatment, personal attention, and a safe and optimally organized environment" (HagaZiekenhuis, z.d.)

Several teams support the board of directors with the day-to-day management of the 24 specialisms of the hospital. One of these teams is the Capacity and Logistics team. This team, consisting of 7 team members track and manage the capacity and logistics of all the specialisms. One of the tasks of this team is to monitor and manage the capacity of COVID-19 beds. Also, the Capacity and Logistics team supervises this research.

One of the 24 specialisms of the HagaZiekenhuis is ophthalmology. The ophthalmology clinic is the largest department of the hospital in the number of patients per day. The average number of unique outpatient clinic patients on a weekday in 2021 is 160 (without considering the scope of this research) (HiX, 2021). These patients visit the clinic to see an ophthalmologist, an optometrist, an assistant, or a combination of these. Examples of the most common health complaints with which patients visit the clinic are subretinal neovascularization (growth of blood vessels under the retina[3]), cataract (clouding of the lens of the eye which reduces vision), and glaucoma (the fibers of the optic nerve are gradually lost). In 2020, cataract surgery resulted in 94,9% of the incidents in better sight of the patients, and in 98,9% of the incidents, the eye test after the surgery was estimated correctly. Nationally, these performance indicators are 94,4% and 95,0% respectively, meaning the Hagaziekenhuis performance is above average.[4]

Figure 1 shows the Organizational chart of HagaZiekenhuis[5]. It highlights the HagaZiekenhuis, the capacity, and logistics team, and the ophthalmology clinic to give context to the organizational structure within the HagaZiekenhuis.

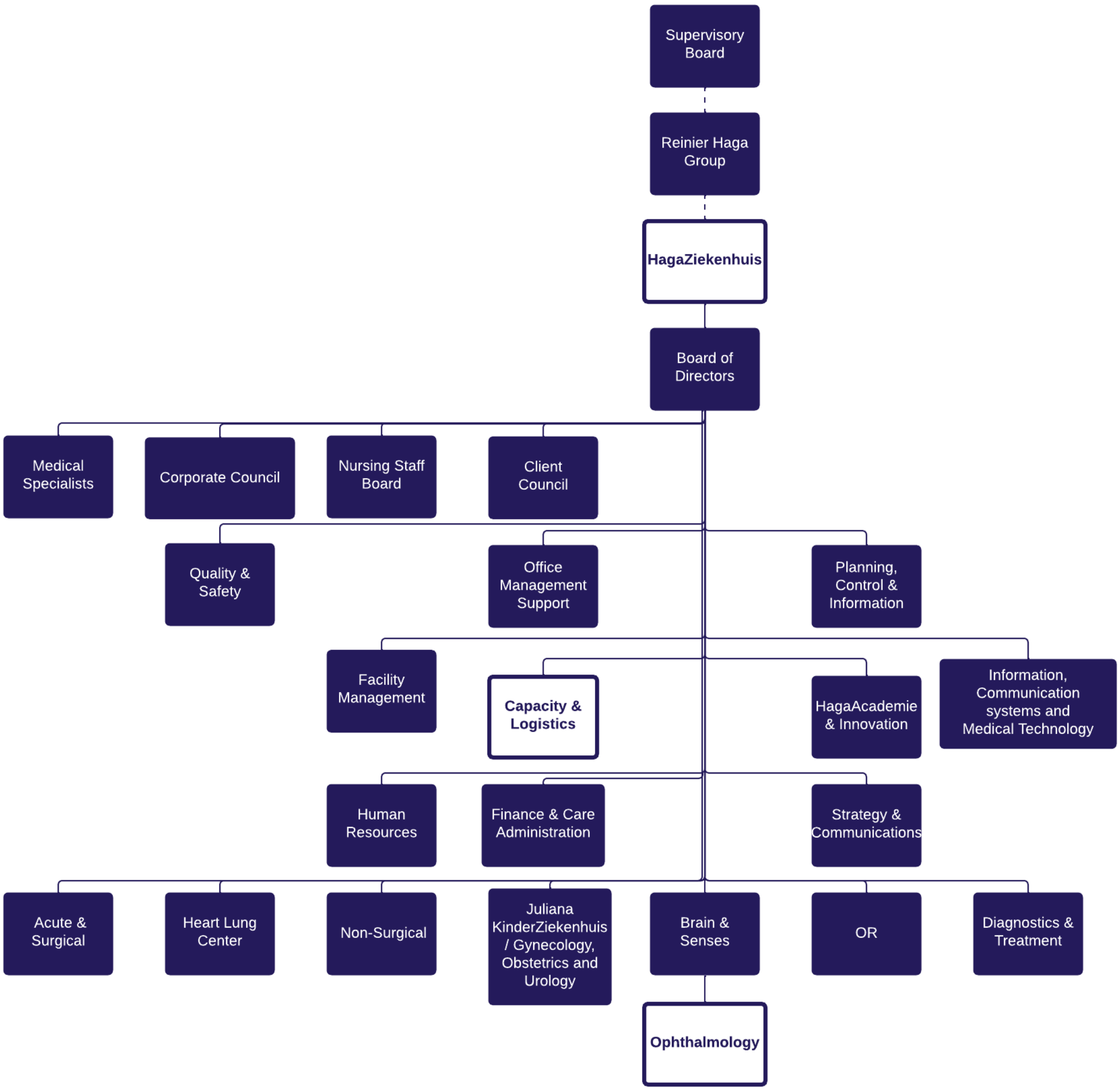

Figure 1 Organizational chart HagaZiekenhuis (Organogram HagaZiekenhuis van Den Haag, 2021)

1.2 CORE PROBLEM

The problem the ophthalmology clinic experiences is an increased workload. The cause of the increased workload has multiple origins. Through observing the clinic and analyzing historic data from the clinic the underlying problems are identified and put into a problem cluster based on cause-effects. Chapter 2 Problem analysis contains a description of choosing the core problem and discusses the different processes at the ophthalmology clinic including the problems mentioned in the problem cluster in further detail.

The central theme of all the problems in the problem cluster is perceived workload variability. Since the core problem preferably is a problem with the highest impact within the limits of the resources and time available, this research merges problems (12) and (13) into one core problem:

There is high variability between the planned duration of appointments and the actual duration of the appointments.

1.3 RESEARCH GOAL

The goal of this research is to provide a proposal of how to reduce the variability in the duration of appointments to decrease the workload of the ophthalmologist while at least remaining the same quality of care.

At the end of this research, we deliver a recommendation on how to optimize the processes of the ophthalmology clinic to the HagaZiekenhuis. This recommendation contains a forecasting and scheduling strategy based on the results of the research and an implementation plan.

1.3.1 Scope

This research considers the ophthalmology outpatient clinic. It does not focus on the clinical operation rooms and/or the treatment room.

As mentioned before, there are three categories of patient visits, ophthalmology, optometry, and other services by assistants. This research focuses mainly on the ophthalmology consultations performed by ophthalmologists. Since the services by assistants in some cases affect the consultations of the ophthalmologists these are relevant for this research as well. Services that do not influence the consultations, as well as the optometry appointments, are out of the scope.

Furthermore, the focus of this research is limited to the planning and logistics of the processes of the ophthalmology clinic. Any medicine or financial-related issue is merely addressed.

1.4 RESEARCH QUESTIONS

To solve the core problem, this research states the research question as:

How to decrease the variability that accrues with planning appointments to decrease the experience of workload by ophthalmologists?

We divide the research question into several sub-questions:

- Q1. What is the context of the core problem?
    - Q1.1 What are the causes of and extent of variability in appointment duration realizations?
    - Q1.2 How does the variability affect the workload experience of staff?

Q1.1 and Q1.2 together construct an answer to Q1. The answer to these questions gives context to the core problem. Section 2.2.6 Problem analysis and demarcation of scope answer these questions. The research approach relies on the context of the core problem. Also, Chapter 6 Conclusion and Recommendations uses this context to propose recommendations.

- Q2. What does the existing literature say about reducing these types of variability?

Chapter 3 Literature Review answers Q2. The literature review contributes to the design of the forecasting and testing approach.

- Q3. How to intervene in the existing planning strategy to reduce variability?

Q2 is the basis for the answer to Q3. It will be answered in two steps. First, Chapter 4 Forecasting and testing approach discusses the intent of the research. Second, Section 5.4 Experiments states the interventions in the existing planning strategy as experiments. The intent of the model and the experiments discussed in Chapter 4 and Section 5.4 answer Q3.

- Q4. What reduction in variability can be realized by the proposed interventions?

The reductions in variability are the results of the experiments in the forecasting and testing model. Chapter 5 Results show these results.

- Q5. How to implement the proposed forecasting and scheduling strategy in the ophthalmology clinic of HagaZiekenhuis?

Q5 is the recommendation for the HagaZiekenhuis based on the research as built-up by the previous questions. Chapter 6 Conclusion and Recommendations discusses the answer to Q5.

2. PROBLEM ANALYSIS

This chapter answers the first research questions:

- Q1. What is the context of the core problem?
    - Q1.1 What are the causes of and extent of variability in appointment duration realizations?
    - Q1.2 How does the variability affect the workload experience of staff?

Section 2.1 describes the ophthalmology process, involved resources, and patient characteristics. Section 2.2 analyzes the current planning and control of the clinic. Section 2.3 analyzes the current performance, focusing on the workload variation, and the variability in appointment duration realizations. Section 2.4 motivates the selection of the core problem. Finally, Section 2.5 gives an overview of the (root causes of the) problems and demarcates the scope of this research. Throughout the chapter, we link the discussed problems to the problems in the problem cluster (see Figure 9) by mentioning their number in the cluster between parentheses.

2.1 PROCESS DESCRIPTION

Figure 2 shows the patient flow from arrival to the end of treatment. In the following subsections, we explain the successive steps in this flow chart.

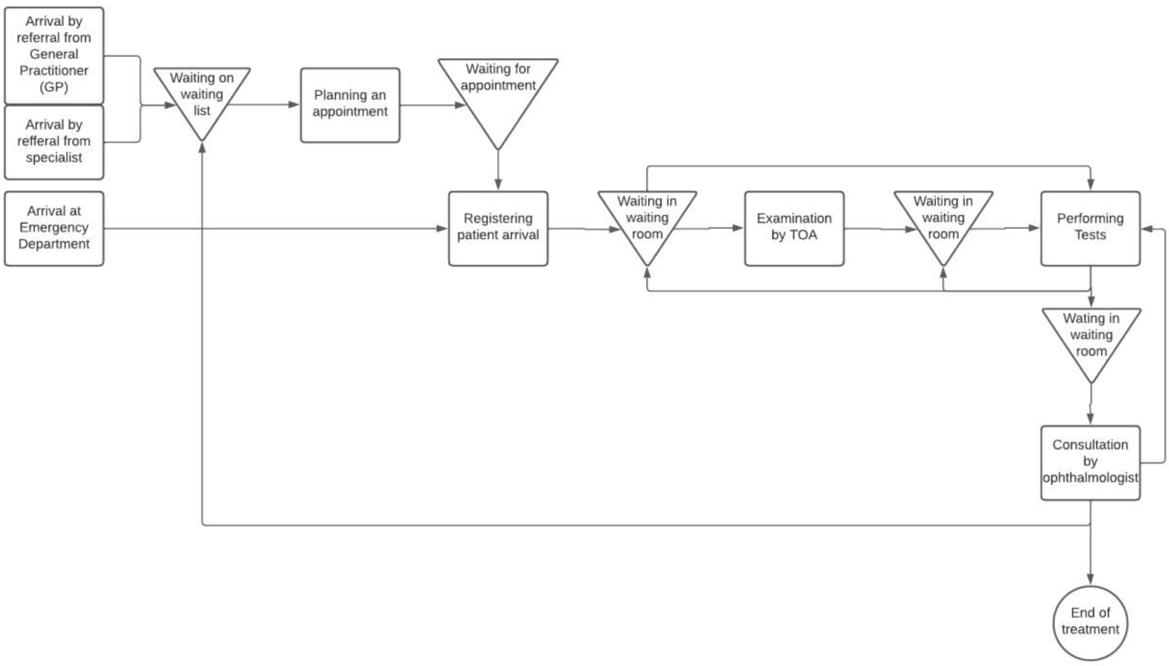

Figure 2 Patient flow in the ophthalmology outpatient clinic

2.1.1 Referral

The patient requires a referral to get an appointment at the ophthalmology clinic. Either a GP or MS delivers a referral. The referral is mandatory for reimbursement of the treatment at the insurance company. The referral contains, among others, a short explanation of the medical complaints of the patients. Based on this explanation and (if any) the medical history of the patient, the patient is put on a waiting list with certain characteristics of the appointment. Characteristics that are determined at this state are Sub Agenda name, appointment code, treating ophthalmologist, maximum access time, and type of patient (new or check-up). The Sub Agenda names are either the name of the ophthalmologist or set to “DIENST”. If a patient has already been assigned to a specific ophthalmologist, for instance when it is a check-up consultation, the Sub Agenda name of the ophthalmologist is assigned to the appointment. If no specific ophthalmologist is already assigned, the Sub Agenda name is set to ‘DIENST’, which means that any ophthalmologist can perform the consultation, or ‘AIO’, which means that the consultation is assigned to an ophthalmologist in training. To decide the maximum access time, an ophthalmologist reviews every referral before entering the waiting list.

2.1.2 First appointment

Section 2.2 get into the planning strategy of the ophthalmology clinic. The appointment date and time are set for the patients on the waiting list by a first come first served policy.

2.1.3 Patient arrival registration

On the date of the appointment, the patient’s ID is checked and arrival is registered at the central registration desks near the entrance of the hospital. If it is the patient's first visit to the hospital he needs to be registered as a patient at the registration desk. After these processes, the patient is referred to the clinic. The clinic has a decentralized registration desk where the arrival and arrival time of the patient is registered. The patient will receive a ticket, indicating the waiting room/treatment room where the patient is expected.

2.1.4 Patient preparation by a TOA

The TOA is a Technical Ophthalmology Assistant who handles the first step in the consultant appointment of the patient. The patient explains the medical conditions to the TOA. Based on these the TOA will decide whether additional tests are necessary to gain more information about the medical condition before the patient sees the ophthalmologist. The TOA will apply a fluid to the eyes of the patient to widen the pupils. If the patient needs additional tests the TOA will register this in the system (HiX) and the patient is sent to the waiting room to wait for these tests.

(2) It is unknown before seeing the patient what actions are necessary for the patient before seeing the ophthalmologist.

The visit of a patient at the ophthalmology clinic starts by default with a conversation with a TOA (technical ophthalmologist assistant). During this conversation, the TOA decides what tests are necessary for the patient to take before seeing the ophthalmologist for the consultation. These tests will take only a few minutes each, and therefore are not planned as separate appointments. Some patients do not need additional tests and will continue to the waiting room, in time for the consultation, other patients need several tests. Assistants perform these tests in a first come first serve order. Therefore, several queues occur at the clinic. Only after waiting for the test and being tested, the patient enters the queue for consultation with the ophthalmologist. Consequently, the effect of problem (2) is (3) an unnecessary delay before the consultation. And as with problem (1), this type of variety results in (16) a workload that is experienced as high.

(9) Number of TOAs is not necessarily related to the number of ophthalmologists.

It is brought to light that the number of TOAs working on a certain day is planned according to an estimation of how many TOAs are needed. However, this estimation is not based on an ophthalmologist/TOAs-ratio. On certain days, with fewer ophthalmologists and more TOAs, the flow of patients is very quick, while on other days the TOAs are the bottleneck of the process. This means that the ophthalmologists need to wait on their patients, causing huge variability in the process times resulting in (11) an unplanned delay. This type of variability that results in (11) contributes to (16) the increased experience of a high workload.

2.1.5 Tests

There are different types of tests that a patient may need to take before seeing an ophthalmologist. The duration of each test is approximately 3 minutes. A patient may need one or more tests. Most of the tests are performed by an assistant. The test results are registered in the patient file. After the tests, the patient is sent back to the waiting room.

(1) The FDT, the short version (30 seconds) of the PERI (20 minutes) is not used as much as it can be used.

PERI is a field of vision test, which takes around 20 minutes. Because of the relatively long test time, PERI is one of the few actions that may be required before consultation with an ophthalmologist, which is planned as a separate appointment followed by the consultation appointment. The Frequency Doubling Technology (FDT) is an alternative field of vision test that will take only 30 seconds, and therefore does not require a separate appointment. However, while this FDT test is available for 5 years now, patients that need a field of vision test are by default planned for a PERI test rather than an FDT, with only a few exceptions. At the arrival of the patient, a decision is made whether the patient will get an FDT or a PERI test, regardless of what is planned for the patient. When an FDT test is performed, it might be that the patient needs the PERI test as well, because of positive or inconclusive results of the FDT test. The likeliness of this happening is small. This causes either a long waiting time for the patient before consultation since their appointment is not consecutive anymore, or it causes a delay for the ophthalmologist since the patient is not ready with the test yet at the time of the appointment. This results in consequence (3) an unnecessary delay before the consultation. Consequently, this type of variety between the planned consultation and actual consultation time contributes to (16) the experience of an increased workload.

(8) There is one flexible staff member regardless of the number of ophthalmologists & (10) Many small actions are performed by one flexible staff member.

After the patient visits the TOA, the patient is sent to the waiting room to get some tests before consultation with the ophthalmologist. The flexible staff member performs a number of these small tests. That means that depending on the number of patients that need a test, a queue forms in the waiting room, where patients wait their turn for their tests. This queue has only one server (flexible staff member). On busy days, this queue can increase to an extent where it will become the bottleneck in the process, meaning the ophthalmologist needs to wait on their patients to get all their tests before their consultation. Therefore, the combination of these problems causes (11) an unplanned delay, leading to an overflow of patients, meaning (16) the workload increases.

2.1.6 Consultation ophthalmologists

Since the test results are loaded in the patient file the ophthalmologist can both see in the system if a patient is sitting in the waiting room and if the patient did the tests that were necessary for the consultation. When the previous patient leaves the ophthalmologist's consultation room the next patient is called in for the consultation. The planned consultation time for a patient is 10 minutes.

(14) Increased average of the consultation times & (12) Increased standard deviation of the consultation times.

Figure 5 shows the change in the average and standard deviation of consultation times. Over 5 years, both increased. The standard duration of a one-time slot remains the same, 10 minutes per time slot for 67% of the appointments. The remaining appointments (33%) have a planned duration other than 10 minutes. The increase in average and standard deviation of the duration means (15) that the actual duration of an appointment differs more from the planned duration than before. Consequently (16) the experienced workload increases.

2.1.7 End of treatment

After consultation, the patient will either be put back on the waiting list for a check-up consultation or the treatment has ended. A check-up consultation happens when a patient's treatment is not finished, and the patient needs further treatment and/or a physical check-up.

2.2 PLANNING AND CONTROL OF THE OPHTHALMOLOGY CLINIC

Planning the actual appointment of a patient happens approximately 4 weeks in advance. It follows directly after the blueprints of the ophthalmologists' agendas are set. This is done by the capacity and logistics team and is based on the availability of the ophthalmologists and the production of the ophthalmology clinic. The empty blueprints of the agendas of the ophthalmologists will be filled according to the waiting list. Apart from the appointment date and time, a definite ophthalmologist is also assigned to the appointment. The characteristics of the appointment are determinant in deciding the date and time of an appointment because of the blueprints of the agendas of the ophthalmologists.

(4) Planning patients is depending on the blueprint of the ophthalmologist's agendas.

Front desk staff plan patients for their appointment according to a waiting list. Based on experience and certain preferences of the ophthalmologists a certain blueprint is loaded into the agendas of the ophthalmologists. Figure 3 shows an example of an empty agenda with a blueprint. These agendas indicate the type of appointment that can be booked in a certain timeslot. That means, when planning patients, the access time, the time between planning a patient and the actual appointment date, is restricted by the type of appointment the patient needs. For instance, when there are 10 new patients on the waiting list, the patients are only planned on the time slots for new patients. Front desk staff will fill the remaining empty time slots with other appointment types only up to two days in advance. As a result, patients may have to wait long, even though there may still be empty time slots in the agendas. Long waiting lists will (16) increase the experience of a high workload.

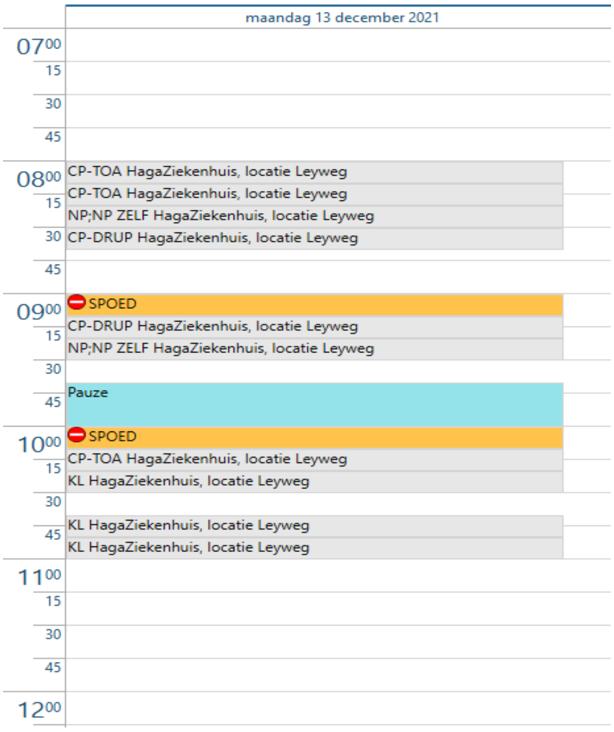

Figure 3 Blueprint of a schedule for an ophthalmologist (HiX, 2016) (NP: new patient appointment, CP: check-up appointment, KL: check-up consultation after surgery)

2.3 PERFORMANCE ANALYSIS

2.3.1 Number of appointments per weekday

Figure 4 shows the number of appointments per weekday. On average, the ophthalmology clinic has 36 appointments per day on a weekday. As indicated by the orange trendline in Figure 4, throughout the years the mean number of appointments has declined.

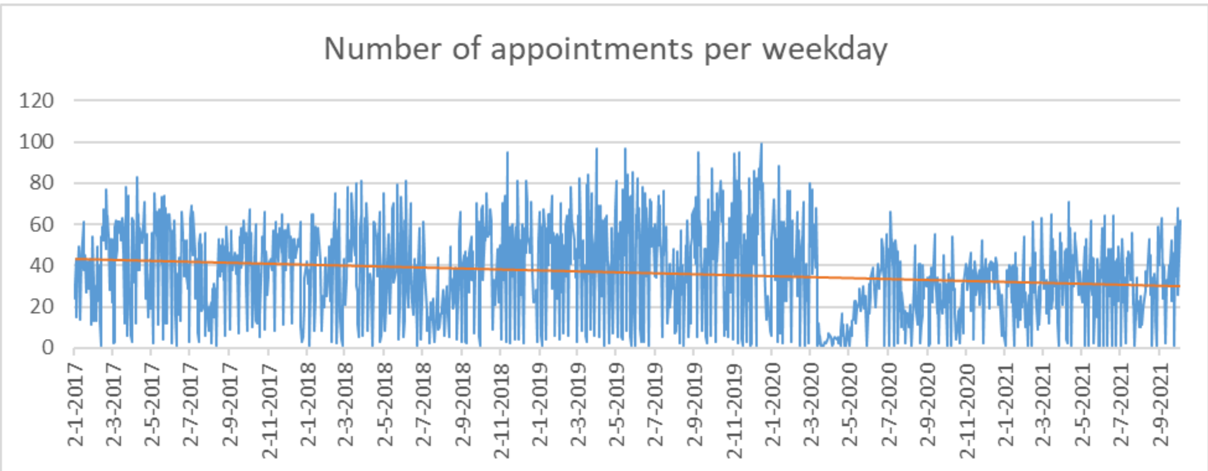

Figure 4 Number of appointments per weekday (HiX, 2021)

2.3.2 Mean and Standard Deviation of the duration of appointments

Figure 5, Figure 6, and Figure 7 show the statistics of the duration of the appointments. On average, the duration is of every appointment 9,26 minutes. However, the standard deviation of these durations is on average 4,35 minutes, meaning there is a relatively high variation, which can be seen by the wide of the boxplots. Both the mean duration and standard deviation increase over the years. Figure 7 suggests that the appointment duration is normally distributed, the distribution is somewhat positively skewed.

Case Summaries

Actual Duration

Year	Mean	N	Std. Deviation	Std. Error of Mean	Variance
2017	8,31	11553	4,270	,040	18,229
2018	9,01	10924	4,315	,041	18,616
2019	9,30	13454	4,187	,036	17,530
2020	10,01	7729	4,350	,049	18,922
2021	10,36	6602	4,453	,055	19,827
Total	9,26	50262	4,349	,019	18,910

Figure 5 Descriptive statistics actual duration (HiX, 2021)

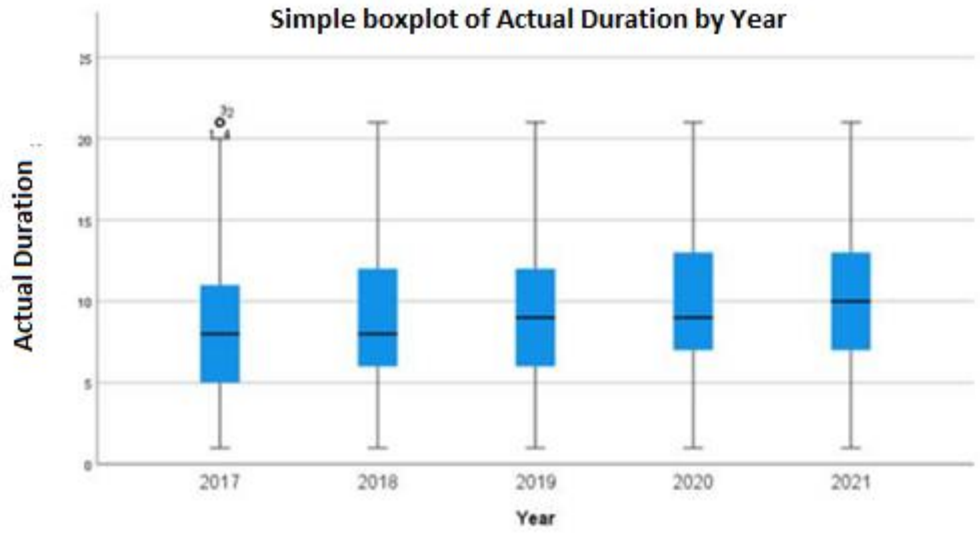

Figure 6 Actual appointment duration boxplots (HiX, 2021)

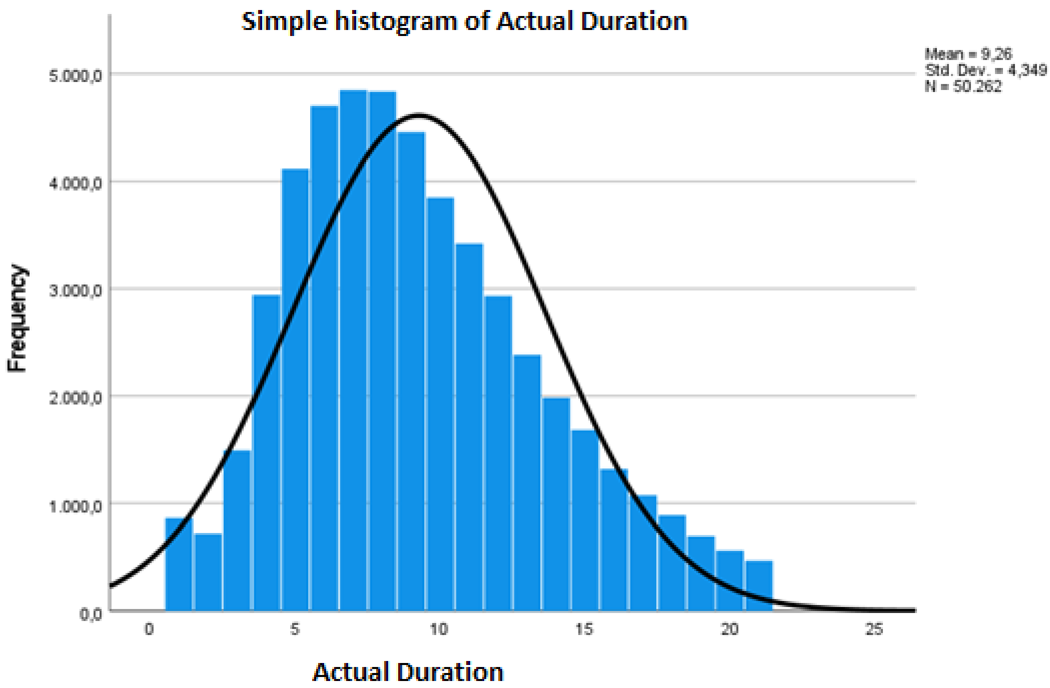

Figure 7 Histogram actual appointment duration 2017-2021 (HiX, 2021)

2.3.3 Error actual duration and planned duration

Figure 8 shows the error between the actual duration and planned duration of the appointments at the ophthalmology clinic in a boxplot. On average, the absolute error is 3,6 minutes, with a standard deviation of 2,6 minutes. This error is an indicator for the running (positive values) and standing still (negative values) of the ophthalmologists at the clinic. The error has a 95% confidence interval of [-9,3;8,2]. The wider this interval, the higher the perceived workload.

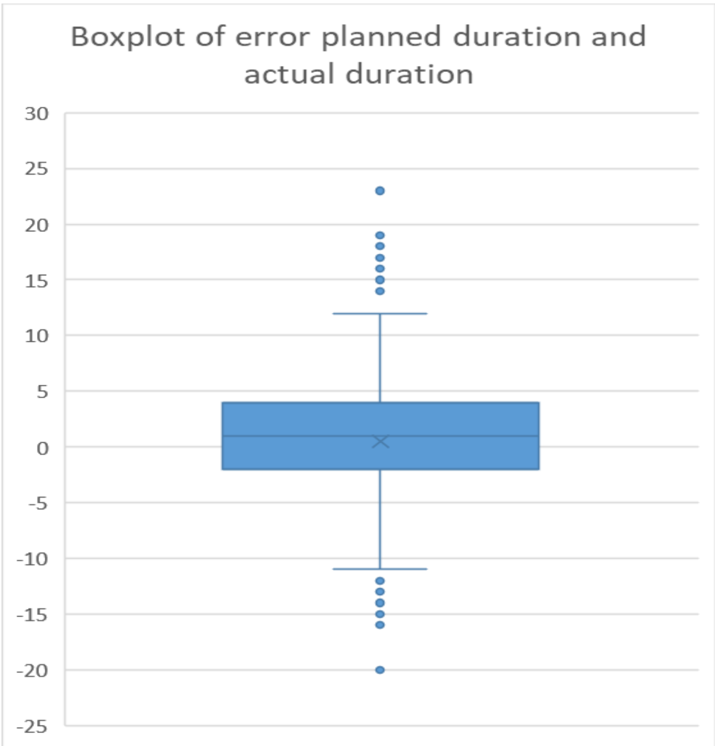

Figure 8 Boxplot of error planned duration and actual duration: 50262 observations (HiX, 2021)

2.3.4 Performance analysis by variable

The number of appointments, as well as the mean and standard deviation of the actual duration, are shown per variable of the appointment. Appendix A lists the abbreviations of the appointment codes.

Table 1 shows that a third of the appointments are for check-up patients. Including the CP-DRUP and CP-TOA, it is even more than 60% of the total appointments. Depending on the appointment code the mean duration of the appointment varies from 8 to 10 minutes, all with a standard deviation between 4 and 5 minutes. Table 2 shows that the actual duration of an appointment segregated by diagnosis code differs more in the mean and standard deviation of the actual duration among the different Sub Agenda names than among the different appointment codes. The same applies to the mean duration among the different diagnosis codes, as shown in Table 3. The standard deviation of the actual duration is on the other hand quite constant, around 4 minutes.

Appointment code	Number of appointments	% of appointments	Mean actual duration	Stdev actual duration
CP	16863	33,6%	9,27	4,23
CP-DRUP	3015	6,0%	9,64	4,58
CP-TOA	13947	27,7%	9,45	4,39
KL	6794	13,5%	8,18	4,08
NP	9643	19,2%	9,59	4,48
Total	**50262**	**100,0%**	**9,26**	**4,35**

Table 1 Performance analysis by appointment code (HiX, 2021)

Sub-agenda name	Number of Appointments	% of Appointments	Mean actual duration	Stdev actual duration
A	4109	8,2%	9,67	4,56
B	10745	21,4%	7,88	3,94
C	4190	8,3%	9,91	4,35
D	6302	12,5%	10,61	4,08
E	2115	4,2%	10,32	5,00
F	1471	2,9%	10,08	4,45
G	4144	8,2%	8,47	4,47
H	7813	15,5%	11,19	3,96
I	9373	18,6%	7,82	3,85
Total	**50262**	**100,0%**	**9,26**	**4,35**

Table 2 Performance analysis by Sub Agenda name (HiX, 2021)

Diagnosis Code	Number of Appointments	% of Appointments	Mean actual duration	Stdev actual duration
103	1938	3,9%	10,07	4,30
155	405	0,8%	8,46	3,85
253	1243	2,5%	10,29	4,17
404	1638	3,3%	10,31	4,31
452	1816	3,6%	9,38	4,15
454	835	1,7%	9,27	4,38
459	1197	2,4%	9,94	4,26
502	2294	4,6%	9,76	4,08
554	9591	19,1%	8,84	4,36
557	822	1,6%	9,65	4,53
607	2860	5,7%	9,49	4,29
654	2802	5,6%	10,00	4,55
657	973	1,9%	10,07	4,51
704	1570	3,1%	9,97	4,32
705	3396	6,8%	9,64	4,57
707	1507	3,0%	9,85	4,28
751	2133	4,2%	7,23	3,72
754	1210	2,4%	8,74	4,01
859	611	1,2%	10,50	4,69
901	2657	5,3%	8,53	4,06
904	7583	15,1%	8,79	4,26
907	1181	2,3%	9,36	4,47
Total	**50262**	**100,0%**	**9,26**	**4,35**

Table 3 Performance analysis by diagnosis code (HiX, 2021)

2.4 SELECTING THE CORE PROBLEM FROM THE PROBLEM CLUSTER

During a period of 3 half-days of observing at the ophthalmology clinic, several problems came up that are direct or indirect caused to the experience of the increase in workload. Also, when analyzing data several statistics indicated the experience of an increase in workload. The problem cluster depicts the cause-effect relations of all the problems that came up during observation or data analysis. Figure 9 shows the problem cluster. Also, Appendix B Problem Cluster and problem List sums them up again. We select a problem as the core problem when it has no underlying causes, is considered solvable within the time and resources available for this research, and has the most impact when solved. This approach is based on the theory of Heerkens (2017)[6].

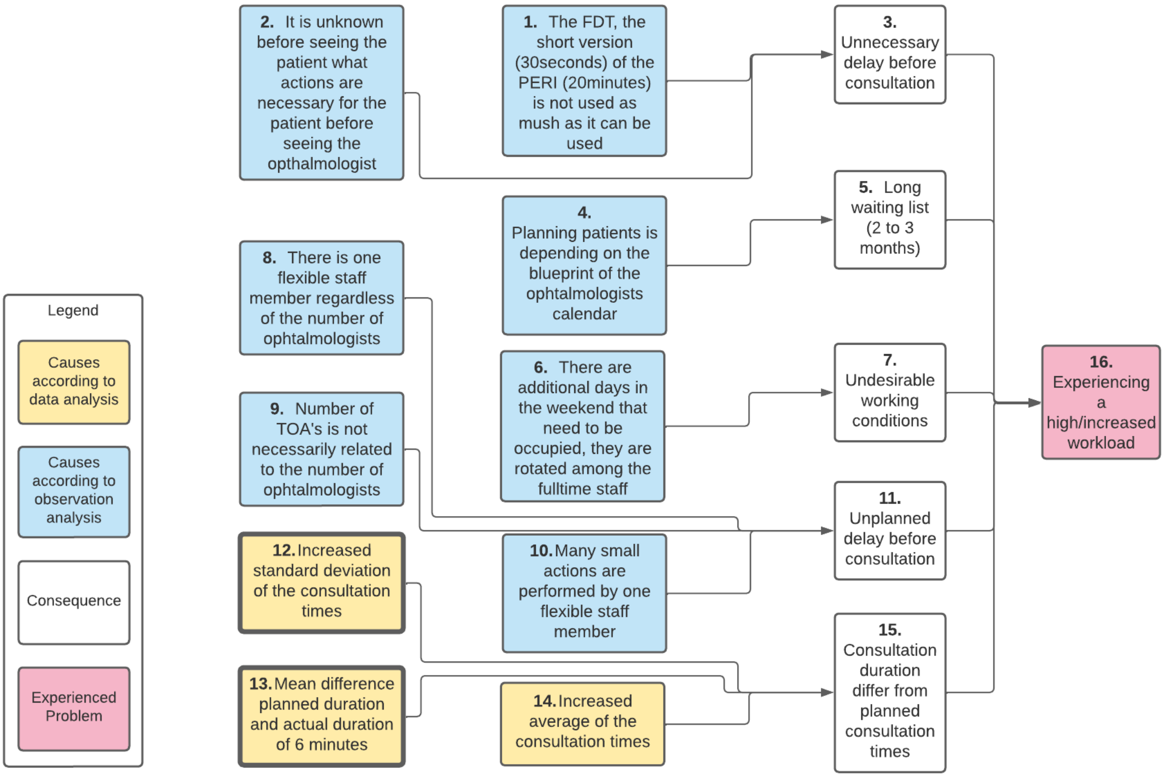

Figure 9 Problem cluster with numbered problems

Underlying problems (1), (2), (4), (6), (8), (9), (10), (12), (13), and (14) all represent some type of perceived variability. The reality differs from the standard, and/or the standard is unknown causing a lack of ability to anticipate and plan. The cause of problem (1) is twofold, on one hand, it is due to a lack of awareness and on the other hand, it is due to an 'unsolvable' problem. Unsolvable, because, like problem (2), it is simply not possible to predict the details of the complaints of a patient before arrival at the clinic. Problem (6) is a human resource issue and does not concern the planning and logistics of the health care processes at the clinic. Therefore, problem (6) is considered out of the scope of this research. The same applies to problems (8) and (9), which are depending on the availability of resources. Furthermore, problem (14) takes place in the consultation room of the ophthalmologist. Their consultation time is depending on the medical aspects of the complaints of the patients. One of the reasons for a longer consultation time than before might be that a patient more often has more complicated complaints. Another reason might be that the ophthalmologist has a different treatment plan. All possible reasons for this problem are medicine-related, and therefore, (14) is considered out of scope for this research.

This leaves problems (4), (6), (12), and (13) as potential core problems, which all relate to the planning process of a patient's appointment. Problem (6) concerns one specific step in the process of a patient's appointment at the clinic, which can be identified as the bottleneck in the process. Problem (4) directly relates to problems (12), and (13), since the blueprints of agendas not only state the type of appointment, but also the duration of the appointment. However, the blueprints of the ophthalmologist's agendas also contain medicine and finance-related targets. Therefore, (4) is not solely a planning and logistics problem.

This leaves problems (12) and (13) as potential core problems. Both problems are planning problems that indicate high variability in duration. Considering the limits of the resources and time available, problems (12) and (13) are merged into one core problem:

There is high variability between the planned duration of appointments and the actual duration of the appointments.

2.5 PROBLEM ANALYSIS AND DEMARCATION OF SCOPE

From the problem analysis as described above, we answer Q1 and summarize the relevant parts of the problem analysis for the continuation of this research.

- Q1. What is the context of the core problem?
    - Q1.1 What are the causes of and extent of variability in appointment duration realizations?

The mean duration of the appointments has a relatively high standard deviation, which is increasing over the years. Through observing the ophthalmology clinic and doing a data analysis we find various problems caused by the variability at the clinic, all mentioned and structured by cause-effect in the problem cluster in Figure 9. Most of these problems are medicine-related or out of scope for this research. The remaining problems, most relevant for this research, are problems (12) and (13), which are merged into the following core problem:

There is high variability between the planned duration of appointments and the actual duration of the appointments.

- Q1.2 How does the variability affect the workload experience of staff?

Currently, the ophthalmology clinic plans all the appointments for 10 minutes, which is based on the overall mean duration (9,26 minutes). This means duration has a relatively high standard deviation (4,3 minutes), which causes high errors between planned duration and actual duration. This error depicts the running and standing of the ophthalmologists. The higher the error, the more ophthalmologist runs or stands still, this increases the experienced workload. The error is visualized in Figure 8. 95% of the observations have an error between -9,3 minutes, and +8,2 minutes.

3. LITERATURE REVIEW

This chapter answers

- Q2. How does the existing literature reduce these types of variability?

Section 3.1 describes the search process. Section 3.2, 3.3, and 3.4 discusses the theory from the selected literature. Section 3.3 concludes with the relevance of the literature for this research.

3.1 SEARCH STRATEGY

The search for relevant literature starts with the Handbook of Healthcare Logistics (Zonderland et al., 2021).[7] This handbook consists of various theoretical approaches put to practice in healthcare processes. It discusses the theory, the research approach, and the results from practice. From this handbook, we search for research concerning variability reduction, resulting in two relevant sections concerning internal variability reduction. Section 3.2 discusses the first, from which we conclude that our current situation concerns an earliness/tardiness model, in which the overall variability can be reduced by applying the smallest variance first rule. Second, as we discuss in Section 3.3, the Case Type Schedule helps to reduce workload by clustering patient appointments.

Successive to the Case Type Schedule approach we want to know what existing literature states about the duration of each of the case type appointments. To keep the results relevant we limit the search to publications of the past 5 years. Therefore, we continue the search approach by using the following search terms in Scopus: TITLE-ABS-KEY (prediction AND service AND time OR duration AND appointment AND outpatient AND clinic) AND (LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018)). This results in 3 hits. Section 3.4 discusses the first hit, about the prediction of service time. The second result is considered irrelevant for this research since it concerns follow-adherence. Section 0 discusses the third hit, which concerns a framework for analyzing and improving the demand, capacity, and access of an outpatient clinic. Section 3.6 answers Q2.

3.2 CASE TYPE SCHEDULE

In an approach to reduce the workload for nurses, van der Voort et al. [8] focused on reducing variability in hospital bed utilization by improving the scheduling of patients in the operating rooms. Their approach consists of a case-type schedule, based on three principles. The first one is, using the existing master surgery schedule, the second one clustering surgeries into cases based on their expected lengths of stay, and the third one leveling the workload of both operating rooms and wards.

This research has a similar goal to reduce workload. The Case Type Schedule approach of van der Voort et al. aligns with this research as it uses a reduction of variability to reduce the workload. This research will use the same approach based on the same three principles, (1) using the existing schedule of ophthalmologists, (2) clustering patient appointments based on average duration, and (3) leveling the workload of the consultation rooms for the ophthalmologists.

3.3 SMALLEST VARIANCE FIRST (SVF)

Otten et al. (2021) give a model-based overview of the literature on the subject of robust surgery scheduling. They discuss three types of variability, internal, external, and artificial. For this research, we only consider internal variability since we assume a blueprint of the ophthalmologists' agendas is a given. Among the internal variability types, they discuss deviation from the schedule. They present an earliness/tardiness (E/T) model that aims to reduce the variability of the start times of surgeries. They conclude from the literature that for various versions of the E/T model, the Smallest Variance First rule results in optimal or reasonable performance for the E/T model.[9]

As the answer of Q1.2 states the type of variability we research the mean and standard deviation of the consultation times. Because of the high standard deviations in duration, the start time of the patient's appointment is unknown beforehand (appointments are scheduled subsequently). If we plan the appointment at a given time but the previous appointment is taking longer than predicted, the tardiness of the model increases. The other way around, if the ophthalmologist has to wait for his next patient when the previous one is finished, we can address this as earliness. Therefore we conclude that this research concerns an E/T model as described by Otten et al.[9]

3.4 SERVICE TIME PREDICTION

Golmohammadi (2021) used Neural Network (NN) modeling to predict the service time in outpatient scheduling.[10] He used this method to predict the duration of an appointment. In their research, the current situation is planning patients in short or long appointment slots based on the type of patient, new or returning. With their NN model, they include more patient and appointment characteristics and differentiate in the appointment lengths more than the two options they use now. Using NN modeling, with cross-validation as a stopping criterion, also counts in the deviation of the appointments when deciding on the appointment duration. This results in a significantly lower mean and standard deviation of the difference between the planned duration and actual duration of an appointment, and therefore reduces the workload experience of the personnel. Golmohammadi [10] also shows that differentiation between appointment types in combination with a better estimation of the duration of each appointment type will reduce variability.

NN is a complex approach from an implementation point of view. It requires a good understanding of both programming and data since it is a complex approach. Furthermore, NN modeling is inflexible since it needs a constant supply of data to train to stay relevant and keep up with changes in the model. Therefore, we will design a static approach, a Monte Carlo simulation, which is easier to implement, and more flexible regarding changes in the underlying processes. Nevertheless, our validation procedure is based on the approach of Golmohammadi [10].

3.5 FRAMEWORK FOR ANALYSIS AND IMPROVEMENT

Van Bussel et al. (2018) used a 6-step framework to analyze and improve the demand, supply, and access of an outpatient clinic.[11] They conclude, that their framework applies to all outpatient clinics. The 6-steps are:

Step 1: Defining and gathering the raw data

Step 2: Analysing the data with basic statistics

Step 3: Identify trends and striking characteristics

Step 4: Evaluate demand, capacity, and access time

Step 5: Create a usable model of future demand and capacity for outpatient decision-makers

Step 6: Formulate conclusions and potential improvements

3.6 CONCLUSION

- Q2. How does the existing literature reduce these types of variability?

The literature relevant for this research describes various tactics to reduce the variation and thus lower the workload experience for the personnel in the process. The interventions to reduce workload are:

- Predict appointment duration based on historic data (Golmohammadi, 2021) [10]
- Use case types to differentiate between patient/appointment types (van der Voort et al., 2021) [8]
- Use Smallest Variance First as a scheduling strategy (Otten et al., 2021) [9]

Furthermore, the 6-step framework of Bussel et al. (2018)[11] can be used to align demand, capacity, and access of the outpatient clinic to eliminate unnecessary delays.

4. FORECASTING AND TESTING APPROACH

This chapter describes the intent of the research based on the theoretical framework of Chapter 3. It answers

- Q3. How to intervene in the existing planning strategy to reduce variability?

First, this chapter points out the choices that are made to optimize the data. Second, it discusses the motivation for the case types. Last, this chapter explains the Monte Carlo Simulation that is used to experiment on the interventions.

4.1 DATA OPTIMIZATION

We use the appointment data from the ophthalmology outpatient clinic. The data originates from an electronic patient file called HiX and contains appointments from January 2017 to September 2021. This research considers the following variables:

- Appointment Date
- Appointment Time
- Planned Duration
- Appointment Code
- Sub Agenda Name
- Diagnosis Code
- Arrival Time To Clinic
- Call to Consultation Time
- Departure Time From Clinic

Because of the size and quality of the data, some choices were made to make the data set useable for this research.

1. Empty data entries for any of the 9 variables were removed.
2. Appointments for the weekend were removed.
3. Appointments planned out of office hours were removed (office hours from 7:30 to 16.30)
4. Appointment codes that were used for less than 1% of the appointments were removed. Additionally, variations of appointment codes that were used less often, were merged with the overarching appointment code (for instance, appointment code KL is a variation of KL. KL1 being a relatively lesser used appointment code, is now merged into KL). The appointment code that remained are:
    - CP
      checkup appointment
    - CP-TOA
      checkup appointment for a patient that has to visit the TOA before consultation with the ophthalmologist

- CP-DRUP
  checkup appointment for a patient that needs eye drops before consultation with the ophthalmologist
- NP
  new patient appointment
- KL
  checkup appointment after surgery

5. The Sub Agenda names that are not currently used, were removed from the data set. Also, Sub Agenda names that were less than 1% of the dataset were removed. Every Sub Agenda name indicates the agenda of an ophthalmologist, except for DIENST, this agenda is used when there is not one particular ophthalmologist assigned to the appointment, therefore this patient can be seen by any of the ophthalmologists. 9 Sub Agenda names remained, which for privacy reasons are named A through I.
6. For the diagnosis codes, the less used diagnosis codes (bottom 20%) are removed.
7. From the remaining data entries, the actual duration of the appointment is calculated (Call to Consultation Time – Departure Time From Clinic). Appointments with a negative or 0 minutes actual duration time are removed from the data set.
8. Finally, a stem-and-leaf diagram is made, using SPSS, with the actual duration as the dependent variable. Every duration of 22 minutes or longer is considered an outlier, and therefore also removed from the data set.

The final data set has 50262 data entries.

4.2 CASE TYPES

As indicated in Section 3.2 this research uses case types based on the duration of an appointment of that type. Three appointment characteristics are selected as predicting variables based on the results of a statistic regression model discussed in Section 5.1.**Fout! Verwijzingsbron niet gevonden.** for the a ctual duration of an appointment:

- Appointment code
- Sub Agenda name
- Diagnosis code

Each predicting variable is split into two sub-variables, high average duration (H) (between 11 and 15 minutes) and low average duration (L) (between 6 and 10 minutes). Each value of each variable is classified as either H or L. Table 4 shows the classification of each value of each variable.

	H	**L**
Appointment code	CP-TOA	CP
	CP-DRUP	NP
		KL
Sub Agenda name	A	B
	C	G
	D	I

	E	
	F	
	H	
Diagnosis code	Remaining…	554
		904
		103
		754
		901
		751
		155

Table 4 Sub-variable partitioning

Since the characteristics of the appointments and therefore sub variable values are known before planning an appointment every appointment has a case type. For instance, LHL means that the appointment has a Low average duration appointment code, a High average duration Sub Agenda name, and a Low average duration Diagnosis code.

4.3 MONTE CARLO SIMULATION OF APPOINTMENTS

To test a new forecasting and scheduling strategy a Monte Carlo simulation is designed. Based on a uniform distribution of the appointment code, the Sub Agenda names, and the diagnosis codes, these characteristics of the appointment and thus the case type are determined for every simulated appointment. Continuing, a random number is drawn from the normal distribution of the corresponding case type. These distributions are determined for every case type using SPSS. The distributions and parameters are discussed in Section 5.2. Any negative number as a result of the normal distribution is corrected to 0, for determining the simulated actual duration of the appointment. A total number of 8000 appointments are simulated, which corresponds to approximately one year.

From this Monte Carlo Simulation, the error of both the currently planned duration and the proposed planned duration is calculated.

4.4 MONTE CARLO SIMULATION OF AGENDA

Using the same parameters we build a second more elaborated Monte Carlo simulation model. In this model, the agenda of one ophthalmologist for one day is simulated. For this simulation, we assume that one blueprint holds for every ophthalmologist every weekday, see Appendix C. The simulation makes 150 replications, to reduce the t-test value below 5%. For this simulation the following pseudocode is used:

```
For each experiment
       For each replication
              Determine ophthalmologist case type
              Fill calendar
              Calculate KPI
       Next replication
Next experiment
```

For filling the agenda the following pseudocode is used:

```
For each time slot
       Determine diagnosis code
       Set case type
Next time slot
For each time slot
       If time slot is planned appointment
              Determine actual duration
       End if
       Determine planned start time
       Planned end time = planned start time + planned duration
       If actual end time previous time slot > planned start time
              Actual start time = actual end time previous time slot
       Else
              Actual start time = planned start time
       End if
       Actual end time = actual end time + actual duration
Next time slot
```

4.5 CONCLUSION

- Q3. How to intervene in the existing planning strategy to reduce variability?

The first step in intervening in the existing planning strategy is to design the forecasting and testing approach. For this research, we build two Monte Carlo simulations. The first Monte Carlo simulation simulates individual appointments, the second simulates a day agenda of one ophthalmologist. The appointments in both simulation models have a case type value. From 50252 observations in the historic dataset, we calculate the distribution of the actual duration for every case.

5. RESULTS

This chapter shows the results of the approach as described in Chapter 4 and therefore answers

- Q4. What reduction in variability can be realized by the proposed interventions?

First, the regression mode,l used to select the three predicting variables of the actual duration, is explained. Continuing, the distributions and parameters of the case types are displayed. Third, the model validation is discussed. Consecutive, we elaborate on

- Q3. How to intervene in the existing planning strategy to reduce variability?

by discussing the experiments. Finally, the results of the Monte Carlo simulation are shown.

5.1 CORRELATION AND REGRESSION

To determine the predicting variables for the actual duration of an appointment, we first find the correlation between the variables we assume to correlate with the actual duration. For this analysis, we changed the nominal variables Appointment Code, Sub Agenda Name, and Diagnosis code to ordinal variables with values 1 (low average actual duration) or 2 (high average actual duration). Table 5 shows the correlation coefficient between every two variables using SPSS. The table also shows that the correlation coefficients are all significant with at least a 5% confidence level, meaning we can assume, with at least 95% confidence, that the variables correlate.

Correlations

		Actual Duration	SAN	DC	AC
Actual Duration	Pearson Correlation	--			
	N	50262			
SAN	Pearson Correlation	,289**	--		
	Sig. (2-tailed)	,000			
	N	50262	50262		
DC	Pearson Correlation	,121**	,200**	--	
	Sig. (2-tailed)	<,001	,000		
	N	50262	50262	50262	
AC	Pearson Correlation	,037**	,050**	-,010*	--
	Sig. (2-tailed)	<,001	<,001	,020	
	N	50262	50262	50262	50262

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Table 5 Correlation between variables (HiX; 2021)

As a means to determine if the case type is significant in predicting the actual duration of an appointment, we use SPSS to make a regression model with these variables as input variables. Table 6 shows that all variables have a P-Value (Sig.) lower than 0,001, meaning every case type is significant in determining the actual duration of an appointment. We can also see that the Sub Agenda name has the biggest effect on the actual duration of an appointment, much smaller, but followed by diagnosis code and then appointment code. If we reason from the analysis discussed in Chapter 2, the ophthalmologist is the most determining variable when predicting the duration of an appointment due to routine habits, but likely also the type of patients and care. The relatively high Pearson correlation value between Sub Agenda Name and Diagnosis Code (Table 5) supports this.

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	4,483	,090		49,849	,000
	AC	,216	,039	,024	5,515	<,001
	SAN	2,386	,038	,274	62,970	,000
	DC	,580	,038	,067	15,339	<,001

a. Dependent Variable: Actual Duration

Table 6 Linear regression model actual duration using SPSS

	Regression Prediction (Min)
LLL	7,67
LLH	8,20
LHL	10,05
LHH	10,63
HLL	7,88
HLH	8,46
HHL	10,27
HHH	10,85

Table 7 Prediction of actual duration per case type based on the regression model

5.2 DISTRIBUTIONS AND PARAMETERS FOR CASE TYPES

Knowing the variables all correlate with each other and are predicting variables to the actual duration, we will use all three variables to determine the case types of the appointments. The case type is a three-letter combination, in which the first letter represents the type of the appointment code (L/H), the second the type of Sub Agenda name (L/H), and the third the type of diagnosis code (L/H). As an example, an appointment with appointment code CP, Sub Agenda name A, and diagnosis code 554, will have case type LHL, see Table 4.

For every case type, a distribution for the actual duration is drawn from the data set. The actual duration is normally distributed for every case type. This is assumed based on the symmetry of both histograms and boxplots shown in Appendix D Histograms and Boxplots. The parameters for the distribution are shown in Table 8 Distribution parameters.

	Average (Min)	Standard Deviation (Min)
LLL	7,74	3,97
LLH	8,71	4,05
LHL	10,06	4,18
LHH	10,27	4,40
HLL	7,24	3,89
HLH	8,19	3,93
HHL	10,75	4,08
HHH	11,17	4,36

Table 8 Distribution parameters

5.3 VALIDATION OF MODEL

To validate the simulation model with the parameters as described in Section 5.2 we perform a two-sample t-test. For this research, we call the simulation of the current situation experiment 0. The null hypothesis is µ_1=µ_2. For the t-test, we compare the mean duration of appointments in the historic dataset to the mean duration of the simulated appointments. Table 9 shows the statistics of both datasets.

	Mean	Std	n
Historic Data	9,93	4,27	199
Simulation model	10,01	4,27	199

Table 9 Simulation Validation

We calculate the t statistic with the following formula:

$$t = \frac{(\overline{x_1} - \overline{x_2})}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

$$t = \frac{(10{,}01 - 9{,}93)}{\sqrt{\frac{4{,}27^2}{198} + \frac{4{,}27^2}{198}}} = 0{,}19$$

At a 0,05 confidence level, the theoretical t value with 398 degrees of freedom is 1,97, and our t-test value is lower, so we conclude with a 95% confidence rate that the null hypothesis is true. Therefore, the simulation model is valid to simulate the scheduling of appointments at the ophthalmology clinic.

5.4 EXPERIMENTS

For the first experiment, we set the planned duration of every appointment equal to the mean duration of the appointment's case type, see Table 10. The next appointment's planned start time is equal to the current appointment's planned end time, rounded to the minute. The blueprint of the ophthalmologist's agenda stays the same. For the second and third experiments, we round the start time of the next appointment to 5 and 10 minutes respectively. Experiments 4 to 6 differ from 1 to 3 by adding the smallest variance first rule to the scheduling approach. As explained in section 5.1.1, we run an addition experiment which runs experiments 0 and 5 depending in the case type of the Sub Agenda name. Table 11 gives an overview of the experiments and their differences.

	Planned for (min)
LLL	8
LLH	9
LHL	10
LHH	10
HLL	7
HLH	8
HHL	11
HHH	11

Table 10 Planned duration experiments

		Planned Duration (min)	Planned Start Time rounded to (min)	SVF
Exp 0		10	1	No
Exp 1		Mean	1	No
Exp 2		Mean	5	No
Exp 3		Mean	10	No
Exp 4		Mean	1	Yes
Exp 5		Mean	5	Yes
Exp 6		Mean	10	Yes
	Case Type (Sub Agenda Name)			
Exp 7	L	10	1	No
	H	Mean	5	Yes

Table 11 Overview Experiments

5.5 SIMULATION RESULTS

We run 150 replications of every experiment to calculate the KPIs. A one-sample t-test shows that after 150 replications the values for the KPIs are on average the same as one individual value (at a 95% confidence level). The following KPIs are calculated as an average of 150 replication, one replication is one ophthalmologist's day (note that there are 30 planned appointments on one ophthalmologist's day:

- Sum Error
  |Actual End Time – Planned Start Time Next Appointment|, for every planned appointment
- Mean Error
  Sum Error / 30
- Sum Waiting Time
  Actual Start Time – Planned Start Time, for every planned appointment
- Mean Waiting Time
  Sum Waiting Time / 30
- Down Time
  Actual Start Time – Actual End Time Previous Appointment, for every planned appointment
- Break Time
  Actual End Time – Actual Start Time, for every break
- Over Time
  Actual End Time – "16:10:00", for every last appointment

Table 12 shows the KPIs as an average of the 150 runs for every experiment. The results are split between ophthalmologists of case types H, and L. Table H&L shows the results of the complete model. For the mean value of every KPI, the results are ranked by color, green meaning the best, white meaning the worst KPI value. From the results, we see that the KPIs show an improvement for the ophthalmologists with a high average duration for every experiment.

For ophthalmologists with a Low average duration, the experiments result in worse KPIs for all experiments, except for a small improvement in break time.

The reason for the lack of improvement in KPIs for Sub Agenda names with type L is that the experiments all try to predict the duration of an appointment better. Since the Sub Agenda name is the most determining variable for this, and case type L indicates that the duration is rather low, we plan the appointments rather closer to each other, meaning we decrease the overall buffer for error. However, better predicting the duration for Sub Agenda names with case type H improves in such a significant way, that the overall model improves too. Note that the L/H ratio for Sub Agenda Names is nearly 50/50.

5.5.1 Experiment 7

Since Sub Agenda names with case type H experiment 5, shows the best results and for Sub Agenda name case type experiment 0, we design an experiment 7 which runs experiment 5 or 0 depending on the case type of the Sub Agenda name. Table 12 and Table 13 show the KPIs of all experiments . Notable is, that in the overall model all KPIs are best for experiment 7, except for the break time and overtime.

These KPIs are most relevant for the workload experience of the ophthalmologists. The t-value of the two sampled t-test between the KPI's of experiments 7 and 0, show that the break time and overtime are not significantly different. This means that the worse result in KPI is irrelevant. The improvement in lower absolute error, lower waiting time and higher downtime however, are significant according to the 2 sampled t-test. Therefore, we conclude that experiment 7, improves the absolute error, waiting time and downtime, while the impact on the break time and overtime are not conclusive.

Table 13 shows the 95% confidence interval of the error (not absolute) of every appointment from every run. Note that, a small confidence interval means that the differences for the ophthalmologists between running and standing still decreases. The smallest confidence interval occurs for experiment 4. However the t-test value shows that the error does not differ significantly from the error of experiment 0, therefore we assume that this improvement not relevant. Table 13 also shows that both the mean value of the error, as the standard deviation of the error decreases for experiment 7. This results in the second smallest confidence interval width. A two sampled t-test shows that this improvement is significantly different from experiment 0.

H		**Exp 0**	**Exp 1**	**Exp 2**	**Exp 3**	**Exp 4**	**Exp 5**	**Exp 6**	**Exp 7**
Abs Error / appointment (min)	**Mean**	**7,24**	**5,47**	**5,88**	**6,41**	**5,24**	**5,72**	**6,43**	**5,29**
	std	2,72	1,90	1,93	2,81	1,85	1,77	1,81	2,18
Waiting Time / appointment (min)	**Mean**	**4,98**	**3,29**	**3,64**	**3,97**	**3,15**	**3,38**	**3,98**	**2,84**
	std	2,50	1,74	1,90	2,70	1,71	1,81	1,75	2,30
Down Time / day (min)	**Mean**	**21,93**	**29,70**	**30,64**	**34,32**	**29,68**	**32,69**	**34,20**	**43,14**
	std	12,46	14,93	14,05	15,32	14,44	14,62	16,00	23,70
Break Time / day (min)	**Mean**	**117,03**	**154,38**	**147,76**	**153,34**	**155,50**	**153,44**	**146,94**	**131,61**
	std	16,40	36,76	36,12	37,63	35,56	36,64	32,87	20,44
OverTime / day (min)	**Mean**	**2,35**	**0,24**	**0,89**	**0,43**	**0,16**	**0,25**	**1,73**	**1,21**
	std	4,88	6,57	5,92	5,52	5,17	4,85	5,25	5,35
L									
Abs Error / appointment (min)	**Mean**	**4,02**	**5,37**	**5,36**	**6,78**	**5,68**	**5,23**	**6,64**	**4,86**
	std	0,74	1,84	1,40	1,95	1,70	1,93	2,00	1,45
Waiting Time / appointment (min)	**Mean**	**1,39**	**3,31**	**3,09**	**4,44**	**3,66**	**3,11**	**4,08**	**2,32**
	std	0,74	1,70	1,36	1,84	1,67	1,76	2,02	1,61
Down Time / day (min)	**Mean**	**55,20**	**28,93**	**33,07**	**29,80**	**25,21**	**31,68**	**35,73**	**47,16**
	std	15,36	12,17	13,26	15,11	12,39	14,65	16,40	21,04
Break Time / day (min)	**Mean**	**146,45**	**150,83**	**149,60**	**143,60**	**150,07**	**150,56**	**151,85**	**135,86**
	std	7,49	39,02	39,12	36,25	37,09	35,93	31,93	17,59
OverTime / day (min)	**Mean**	**-1,10**	**2,73**	**0,21**	**1,35**	**1,13**	**0,70**	**0,46**	**0,39**
	std	5,69	6,97	4,60	5,28	5,18	4,94	5,67	6,25
H&L									
Abs Error / appointment (min)	**Mean**	**6,02**	**5,43**	**5,68**	**6,55**	**5,40**	**5,54**	**6,51**	**5,13**
	std	2,69	1,87	1,76	2,52	1,81	1,84	1,88	1,94
Waiting Time / appointment (min)	**Mean**	**3,62**	**3,30**	**3,43**	**4,15**	**3,34**	**3,28**	**4,02**	**2,64**
	std	2,67	1,72	1,73	2,41	1,71	1,79	1,85	2,07
Down Time / day (min)	**Mean**	**34,57**	**29,41**	**31,56**	**32,60**	**27,98**	**32,31**	**34,78**	**44,66**
	std	21,14	13,91	13,76	15,35	13,82	14,59	16,12	22,74
Break Time / day (min)	**Mean**	**128,21**	**153,03**	**148,46**	**149,64**	**153,43**	**152,35**	**148,81**	**133,22**
	std	19,81	37,54	37,17	37,29	36,12	36,28	32,49	19,45
OverTime / day (min)	**Mean**	**1,04**	**1,19**	**0,63**	**0,78**	**0,53**	**0,42**	**1,25**	**0,90**
	std	5,45	6,81	5,45	5,44	5,18	4,87	5,43	5,70

Table 122 KPI results Experiments

	exp 0	exp 1	exp 2	exp 3	exp 4	exp 5	exp 6	exp 7
Error / Appointment								
Mean (min)	3,13	3,02	3,13	3,84	3,07	2,89	3,72	1,50
Std (min)	7,06	6,24	6,40	7,39	6,05	6,28	7,15	6,23
Lower Bound (min)	-10,72	-9,21	-9,41	-10,65	-8,79	-9,42	-10,30	-10,71
Upper Bound (min)	16,98	15,24	15,67	18,34	14,93	15,20	17,73	13,71
Width (min)	27,70	24,46	25,08	28,99	23,72	24,62	28,03	24,42
t-value		0,80	0,02	4,59	0,41	1,65	3,84	11,43

Table 13 95% confidence interval error

5.6 CONCLUSION

- Q3. How to intervene in the existing planning strategy to reduce variability?

As discussed in Chapter 4 we build a Monte Carlo simulation model of the agenda of an ophthalmologist to make interventions in the existing planning strategy. The interventions, in the simulation, referred to as experiments, are better predictions of the duration of an appointment with an appointment time round up to respectively 1, 5, or 10 minutes. And the same experiments but additionally using the SVF rule. As a 7^{th} experiment, we add the experiment where we use experiment 5 explicitly for Sub Agenda names of case type H and no experiment for Sub Agenda name case type L.

- Q4. What reduction in variability can be realized by the proposed interventions?

The results of the experiments discussed in this chapter show that for Sub Agenda name case type L, the interventions do not reduce the type of variability that lowers the workload experience of the ophthalmologists. However, for Sub Agenda name case type H, experiment 5 shows the best results in KPI's. Experiment 7 is an experiment that combines experiment 0 and 5. This experiment shows inconclusive results for the break time and overtime. However, the downtime increases while the absolute error and waiting time decreases. Also, the confidence interval is smaller and lower for experiment 7 as can be seen in Table 13. The overall model shows less reduction but improves the current situation nevertheless because the reduction that can be realized by Sub Agenda name case type H has a high impact on the overall model.

6. CONCLUSION, RECOMMENDATIONS, AND DISCUSSION

This chapter sums up the conclusions drawn from the results of the research approach from Chapter 5. Continuing the conclusion is translated into a recommendation for the ophthalmology clinic of the HagaZiekenhuis. With that, this chapter answers

- Q5. How to implement the new forecasting and scheduling strategy in the ophthalmology clinic of HagaZiekenhuis?

6.1 CONCLUSION

6.1.1 Sub Agenda name is the most determined in predicting the duration of an appointment

From the correlations and regression in Section 5.2, we can conclude that the most determining variable in appointment duration is the ophthalmologist. Also, the results from Section 5.5 show that the experiments show particularly good results for the ophthalmologists with an average high duration.

6.1.2 Absolute error declines

The absolute error represents the accuracy of planning an appointment. Since the absolute error per appointment declines most when simulating experiment 7, this experiment plans the appointment most accurately. Experiment 0 shows an absolute mean error of 6,02 minutes, while experiment 7 has an absolute mean error of 5,13 minutes.

6.1.3 Narrow E/T width

The best representation of the decrease in workload experience is the narrow E/T width. Experiment 7 results in the narrow E/T width of 24,4 minutes. Also, the mean error declines from 3,13 minutes in the current situation to 1,50 minutes when running experiment 7.

6.2 RECOMMENDATIONS

6.2.1 Plan on the predicted duration, with a planned start time rounded to 5 minutes

Experiment 7 results in the best KPI scores. Therefore, we recommend for Sub Agenda name case type H to plan every appointment for the duration of the mean duration of its case type. Furthermore, the planned start time of the appointment is rounded to 5 minutes and the SVF rule should be applied when scheduling the appointments. For Sub Agenda name case type L, we recommend to not change the current situation.

6.2.2 Implementation process

Determining case types

This research selected the most relevant Sub Agenda names, appointment codes, and diagnosis codes. When implementing the proposed strategy, the ophthalmology clinic should determine per variable if the mean duration of such an appointment is high or low. This can be done, by calculating the mean duration using HiX. If there is no historic data available to determine the case type, a planned duration of 10 minutes can be used.

Mean durations can be recalculated once a year, to anticipate shifting mean durations or case types per variable.

Planning appointments

When filling the agendas of the ophthalmologists the challenge is to automate the determination of case type based on the diagnosis code. Also, the planned start time should be rounded to 5 minutes. This can be challenging since the planning of appointments happens not necessarily in consecutive order of the ophthalmologist's blueprint. A way to approach this challenge is to communicate the planned start time of an appointment to the patient when the whole day is filled.

6.3 DISCUSSION

The results of this research are influenced by unavoidable circumstances. Also, the assumptions made during this research limit the applicability of the recommendations. This part of the report sums up the most appointable limitations of this research and their consequences for the applicability of the recommendations.

6.3.1 Diagnosis code

This research assumes a known diagnosis for every appointment, before planning the appointment. In practice, this is not always realistic. For new patients, the GP or specialist has to describe the patient’s complaints, however, the real diagnosis is known after the first appointment. Therefore, while it is possible to make a good guess, the case type is definite only for KL and CP appointments. This is considered not that much of a problem since the correlation analysis shows that the diagnosis code as a predicting variable has the lowest impact on the actual duration of an appointment.

6.3.2 Scope

During the data optimization phase of this research, we narrowed the scope to the most relevant Sub Agenda names, appointment codes, and diagnosis codes. At the ophthalmology clinic, the problem is much larger. Further research into a larger scope should determine if the improvements by the recommendations are of the same extent.

6.3.3 Alternative predicting variables

HiX stores a lot of information about appointments in the database. Not every variable is used in this research. For instance, the age of a patient could be a possible predicting variable. Performing the correlation analysis and regression modeling into other variables could extend this research. Note that if this results in more predicting variables, not all predicting variables have to be included as a case type. The practicability of the implementation should be considered. Therefore, select the most determining predicting variables.

6.3.4 2020 and 2021 data

The appointment data from 2020 and 2021 are a huge part of the dataset which is used in this research. However, during these years the COVID-19 pandemic had a huge impact on health care. While the impact on the ophthalmology clinic seemed negligible, the real impact is unknown. Since the most recent appointment data is used to validate the model, it is possible that the simulation model is not accurate in predicting the upcoming year.

6.3.5 Production

As a last discussion point to this research and the recommendations for the HagaZiekenhuis, we would like to stress that more downtime and break time, and less overtime do not equal more production. This research merely focuses on lowering the workload experience of the ophthalmologists and thus lowering the differences between running and standing still. We discourage the HagaZiekenhuis to change (adding or reduce) production. To even out the differences in the downtime between the Sub Agenda names of case types L and H, we rather recommend conducting further research into why certain ophthalmologists take longer for an appointment than others and how to even this out.

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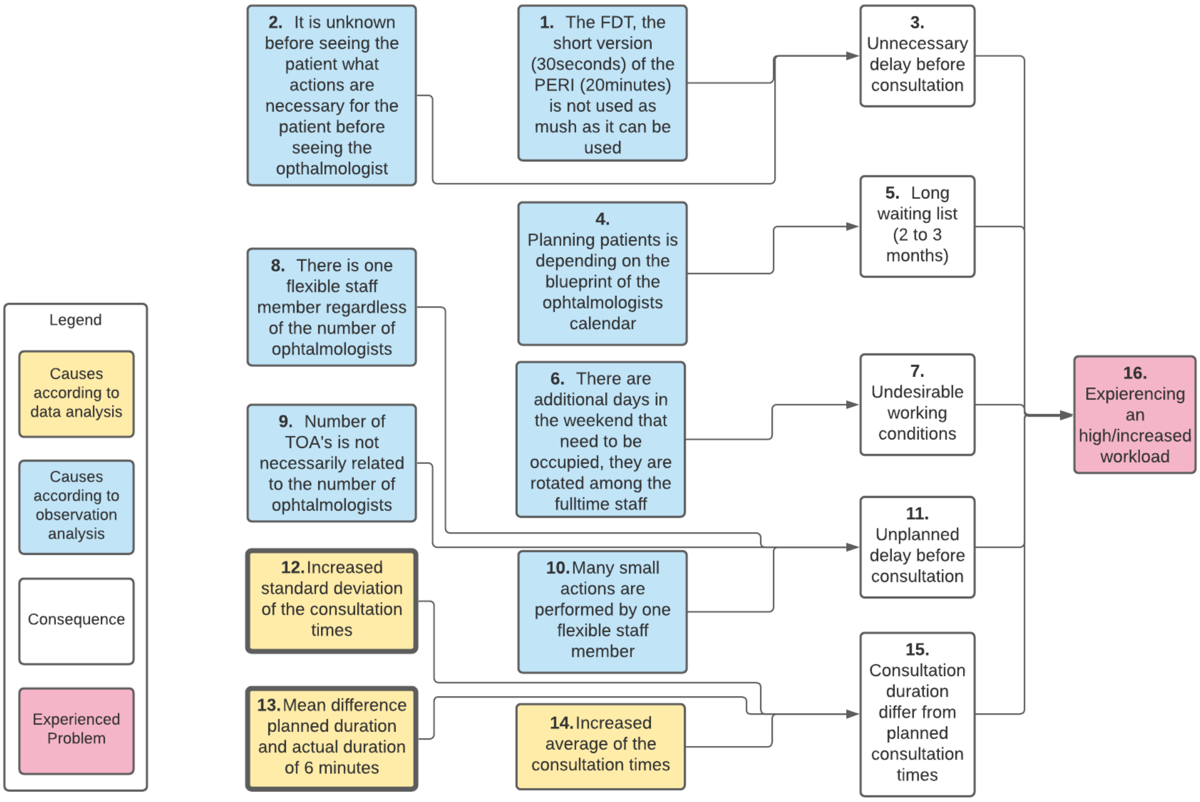
APPENDIX A LIST OF TERMINOLOGY AND ABBREVIATIONS

- **Subretinal Neovascularization**
  growth of blood vessels under the retina
  (Kesen & Cousins, 2010)
- **Cataract**
  a clouding of the lens of the eye or of its surrounding transparent membrane that obstructs the passage of light [5]
- **Glaucoma**
  a disease of the eye marked by increased pressure within the eyeball that can result in damage to the optic disk and gradual loss of vision[6]
- **CP**
  checkup appointment
- **CP-TOA**
  checkup appointment for a patient that has to visit the TOA before consultation with the ophthalmologist
- **CP-DRUP**
  checkup appointment for a patient that needs eye drops before consultation with the ophthalmologist
- **NP**
  new patient appointment
- **KL**
  checkup appointment after surgery

APPENDIX B PROBLEM CLUSTER AND PROBLEM LIST



16. Experiencing a high/increased workload

- **3.** Unnecessary delay before a consultation
  - **1.** The FDT, the short version (30 seconds) of the PERI (20 minutes) is not used as much as it can be used
  - **2.** It is unknown before seeing the patient what actions are necessary for the patient before seeing the ophthalmologist
- **5.** Long waiting list (2 to 3 months)
  - **4.** Planning patients is depending on the blueprint on the ophthalmologist's agenda
- **7.** Undesirable working conditions
  - **6.** There are additional days on the weekend that need to be occupied, they are rotated among full-time staff
- **11.** Unplanned delay before a consultation
  - **8.** There is one flexible staff member regardless of the number of ophthalmologists
  - **9.** Number of TOAs is not necessarily related to the number of ophthalmologists
  - **10.** Many small actions are performed by one flexible staff member

15. Consultation duration differ from planned consultation times

- **12.** Increased standard deviation of the consultation times
- **13.** Mean difference between planned duration and actual duration of 6 minutes
- **14.** Increased average of the consultation times

APPENDIX C BLUEPRINT OPHTHALMOLOGIST AGENDA

08:00:00	CP-TOA
08:10:00	CP-TOA
08:20:00	NP
08:30:00	NP
08:40:00	CP-DRUP
08:50:00	CP-DRUP
09:00:00	Break
09:10:00	CP
09:20:00	CP-TOA
09:30:00	NP
09:40:00	NP
09:50:00	CP-TOA
10:00:00	KL
10:10:00	Break
10:30:00	KL
10:40:00	KL
10:50:00	KL
11:00:00	CP
11:10:00	CP
11:20:00	CP-TOA
11:30:00	Break
13:00:00	SP
13:10:00	OPTO
13:20:00	CP-TOA
13:30:00	CP-TOA
13:40:00	NP
13:50:00	Break
14:00:00	CP-TOA
14:10:00	CP
14:20:00	NP
14:30:00	CP
14:40:00	CP
14:50:00	Break
15:10:00	CP
15:20:00	SP
15:30:00	CP
15:40:00	Break
15:50:00	CP
16:00:00	CP
16:10:00	

APPENDIX D HISTOGRAMS AND BOXPLOTS

Case Type	Referred to as:
LLL	1
LLH	2
LHL	3
LHH	4
HLL	5
HLH	6
HHL	7
HHH	8

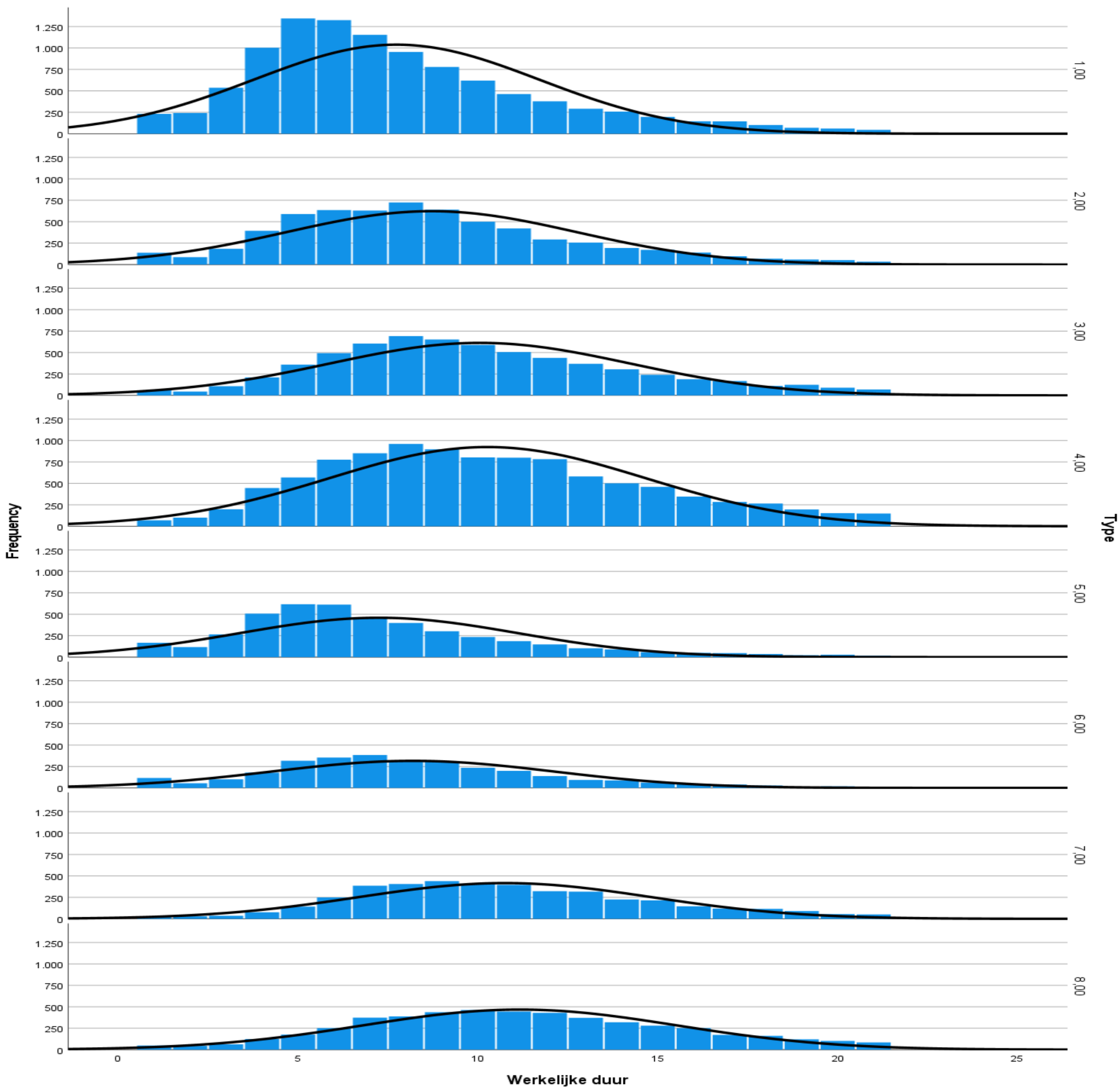


Figure 10 Histogram per case type

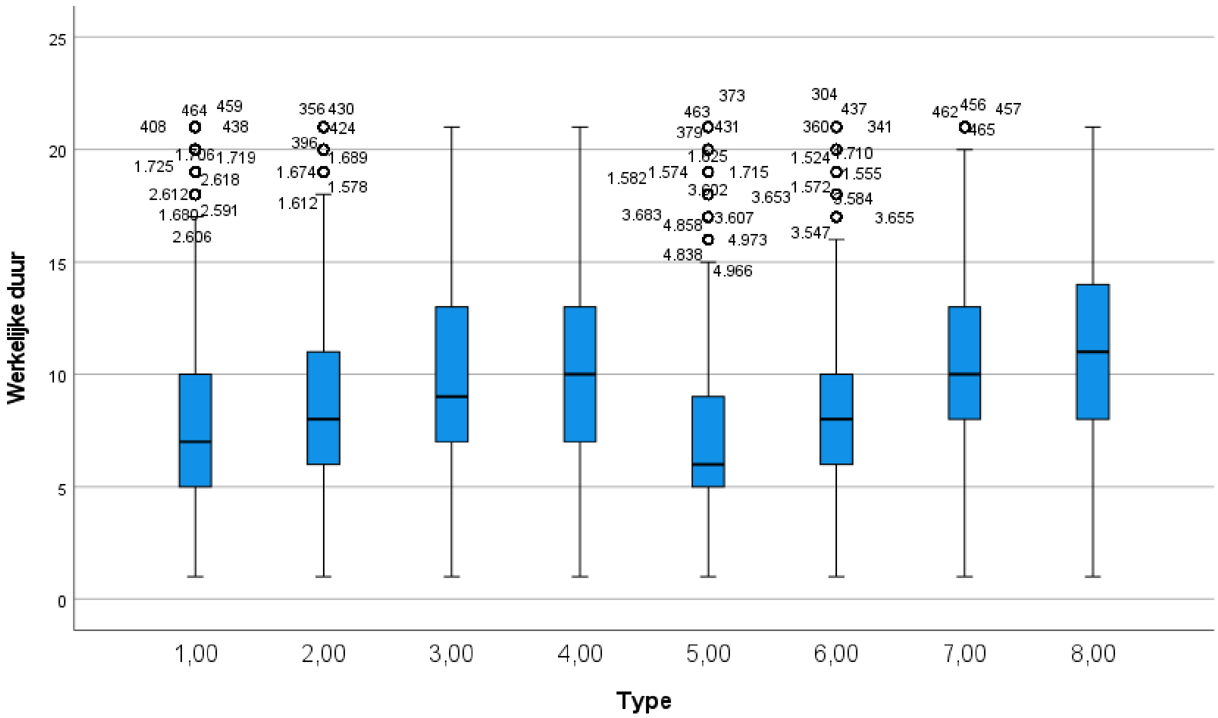


Figure 11 Boxplots by case type