MASTER THESIS

Workload balancing of the Plastic Surgery Department

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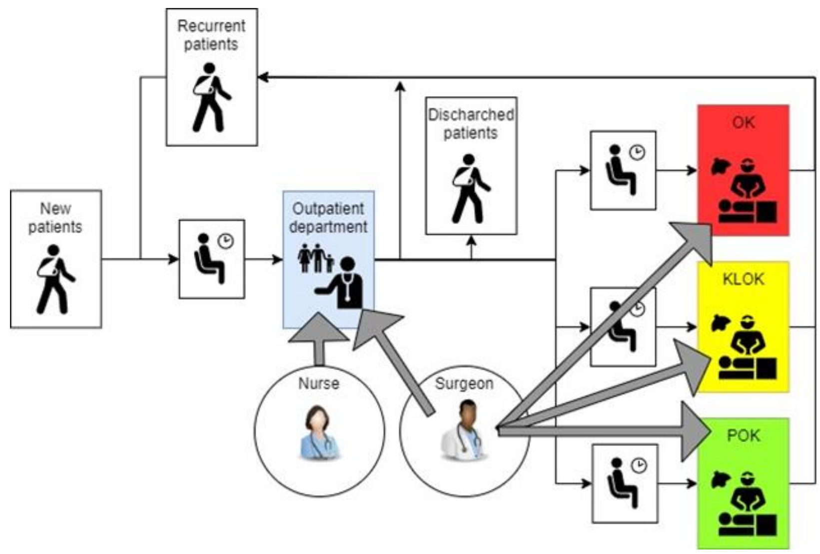
Management summary

Problem definition and context

The plastic surgery department in the Deventer Ziekenhuis suffers from unbalanced workloads, where surgeons, nurses, planners, and secretaries define working at the outpatient department as "running or standing still". The perceived workload is particularly high during time blocks for new patients in the outpatient department. Peaks of new patient arrivals also cause peaks in downstream servers like the Operating Room (OR) and subsequently in the outpatient department for recurring patients, magnifying workload variability.

Tactical block scheduling is done according to a blueprint Block Allocation Schedule (BAS). The BAS allocates each of the four surgeons to work at one server, being:

- the outpatient department,
- the OK (normal operating room),
- the KLOK (secondary small operating room) or;
- the POK (outpatient operating room located in the outpatient department).



The blueprint BAS does not mitigate peaks in new patient arrivals nor reflects the capacity used in practice. Therefore, the goal of this study is:

To develop prospectively validated recommendations for the plastic surgery department to balance workloads and optimise flow.

Approach

This study proposes a workload balancing approach which combines a heuristic and Monte Carlo simulation. The discrete and static simulation model with stochastic patient arrivals and transition matrix evaluates a BAS for a single surgeon in terms of access times and utilisations at each server. Furthermore, a workload balancing algorithm uses the simulation model to iteratively increase the utilisations of servers until a capacity threshold is met, thereby levelling the utilisations. The BAS with levelled utilisations is tested for its robustness by simulating the surgeon's absence for one, two, or three consecutive weeks, and evaluating the time it takes for the operational performance to recover from the perturbations.

Results

The simulation of the currently used blueprint schedule could not reach a steady state, indicating a shortage of capacity in one or more servers. This is confirmed by historic data from 2017, 2018 and 2019, which shows more capacity is used in real-life than the blueprint schedule suggests.

The workload balancing algorithm generated an improved BAS, which has more balanced utilisations compared to the currently used BAS and access times complying with the Treeknormen. Furthermore, the new BAS is more robust than the existing one, as it reduces the time it takes for the system to stabilise after a one, two or three weeks perturbation.

		Historic data schedule	Workload balanced BAS
Simulated steady state utilisation	Outp. dept.	71,7%	73,5%
	OK	69,9%	70,9%
	POK	84,9%	74,1%
	KLOK	n.a.	n.a.
Access times (calendar days)	Outp. dept. New patient	2,8	2,8
	Outp. dept. Recurring patient	3,3	3,3
	OK	7,5	10,7
	POK	16,8	13,9

Performance comparison between schedules

	Surgeons absence		
	One week	Two weeks	Three weeks
Average reduction of utilisation perturbations	91%	47%	39%
Average reduction of access times perturbations	50%	41%	16%

Average reduction of perturbations

Conclusions

The departments blueprint schedule does not hold enough capacity to keep access times within the norms. This study proposes a BAS to level the utilisation per server, thereby balancing the surgeon's workload. Consequently, secretaries' and nurses' workloads will expectantly balance out. The patient's access times comply with the Treeknormen. The proposed BAS is more robust in terms of shorter perturbations after the surgeon's absence, indicating better flow.

Discussion

In this study simulations are performed with one surgeon. To evaluate the combined results for more surgeons the algorithm could be expanded. For further research we recommend using our approach in a multi-surgeon setting, complying with norms for access times first and secondly balancing workloads by levelling utilisations amongst surgeons and servers. The expanded algorithm's purpose is to find a BAS for each surgeon where all access times comply with the Treeknormen and with server utilisations, and thus workloads, as levelled as possible. Optionally a capacity cap for a certain server may be used, for example when the OK only provides a limited number of blocks to the department. When the algorithm results in access times violations caused by the limited OK capacity, it is a good starting point for discussions with the OK capacity allocator.

<u>Contribution to science</u>

To the best of our knowledge the physician scheduling problem was not solved with a Monte Carlo simulation study and workload balancing algorithm before this study. The context of this study was a surgical department. The scope of the research is the care chain process of the patient from the first to last appointment in the department.

<u>Contribution to practice</u>

As a result from the problem analysis in this study, the hospital already adjusted their outpatient department blocks to mixed blocks for new and recurrent patients. Scheduling mixed blocks is easier for the planner and scheduling patients in mixed blocks is easier for secretaries. Mixed blocks reduce peaks in the number of new patients and subsequently peaks in demand downstream. This resulted in lower perceived workloads for surgeons, secretaries, and the planner. Furthermore, mixed blocks are perceived to have less overtime. The workload balanced BAS allows the department to improve utilisations, comply with the Treeknormen and reduce the effects of absence perturbations even further.

Preface

This report is the result of my master thesis project in the plastic surgery department of the Deventer Ziekenhuis. It marks the end of my study period at University of Twente. The university, and in particular the department Industrial Engineering And Business Information Systems gave me the best platform to do these studies. It was not always easy to combine work and a fulltime study, yet I always felt the flexibility that can be expected from a department at the forefront of planning and decision-making research. However, the greatest and best help were the people that make up the department, and I would like to thank all of you. In particular, Erwin Hans, for your enthusiasm, personal engagement, and showing there is always a way out of a problematic situation. Robin Buter, for your critical thinking and feedback. And for both Erwin and Robin, the (free) time you spent on helping me.

I thank Saskia Koemans and Bart Gietema for their feedback and the good atmosphere in the Deventer Ziekenhuis. The balancing act between management, surgeons, and available capacity continues to intrigue me and you gave me the opportunity to explore it. I thank all other colleagues at the Deventer Ziekenhuis for their warm welcome and openness.

I thank all students that became friends, during the studies and thesis project.

I thank all my other friends that supported me during my studies. Sometimes your support was a listening ear, sometimes it was to have a little break from studying, but I always enjoyed your company, appreciated your feedback, and your help, for both study and non-study related problems.

To my family, which includes those by marriage, I thank you all for your support. The way of support was different for all of you, but we proved that we can rely on each other like a family should.

Last, but most importantly, I thank Anne. You ran rings around me to make sure I could combine work and studying, also when you had stressful times yourself. I'm not sure if I can, but I will try to make up for all hardship.

Nieky Post

Hengelo, August 2021

Content

Glossary of terms

DZ	Deventer Ziekenhuis
NP	New patient
CP	Recurrent patient
OD	Outpatient department
OK	Operating room department
KLOK	Secondary (small) operating room
POK	Operating room in the outpatient department
CTS	Carpal tunnel syndrome
OR-complex	Operating room complex
HDC	Hand diagnostic centre
EMG	Electromyography
Block	Amount of time allocated to a surgeon or group of surgeons at the OD, OK, KLOK or POK. Blocks are usually one-half to a full day in length.
Slot	Amount of time in an agenda reserved for a consultation or surgery.
Care pathway	Sequence of activities that are required for a patient.
Same day consultation	Multiple consultations for one patient that are scheduled on the same day.
BAS	Block Allocation Schedule = list of 60 surgeons to server allocations (six weeks long)

1. Introduction

Surgeons, nurses, and secretaries working at the plastic surgery outpatient department of the Deventer Ziekenhuis (DZ) are dissatisfied with their perceived workload: they feel like their workload is unevenly distributed during the day and across weeks. This research aims to find a method for solving these problems.

This chapter introduces the hospital and department where this research takes place in Section 1.1, followed by a description of the problems that the department perceives in Section 1.2. Section 1.3 states the research goal. The research questions are in Section 1.4.

1.1 Background information

Figure 1 - Deventer Ziekenhuis

The Deventer Ziekenhuis (DZ) is a medium sized hospital in Deventer with 2380 employees (1916 FTE), 371 beds, 19164 surgeries and a revenue of €226,986,000 in 2018 (*Jaarverslag Deventer Ziekenhuis*). The hospital has several specialised departments, one of which is the plastic surgery department.

Patients referred to the plastic surgery department have treatments involving restauration, reconstruction or alteration of the human body. This can be either reconstructive or cosmetic surgery. The surgeries most performed in DZ include hand surgeries such as treatments for carpal tunnel syndrome (CTS), trigger fingers and ganglia. Other surgeries involve eyelid corrections, breast reductions and reconstructions.

DZ's plastic surgery department has four plastic surgeons who perform consultations for new patients (NPs) and recurrent patients (CPs). Consultations are performed in the outpatient department (OD). Surgeries are performed in either a conventional operating room (OK), the small operating room (KLOK) or the operating room positioned in the outpatient department (POK). To clarify, the KLOK is located at the operating department of the hospital and has the same specifications as a conventional OK, except for the smaller room size.

The plastic surgeons and the department's operational manager are responsible for the operations of the plastic surgery department and are therefore the problem owners. Together they formulated the thesis assignment for this research. The student writer of this thesis is embedded in the department to observe the processes in the department at first hand.

1.2 Problem description

This section introduces the perceived problems by the plastic surgery department.

Running and standing still

Surgeons, nurses, and secretaries at the plastic surgery department perceive the working pressure at the outpatient department as very busy at one daypart and quiet the other. They also perceive high and low workloads in different weeks. Dayparts and weeks with high numbers of new patients are perceived as particularly stressful. Fluctuating numbers of new patient arrivals combined with the departments planning method may cause the unevenly distributed workload.

Planning methods

The basis for tactical planning of OD-, OK-, KLOK- and POK-blocks is a blueprint for a 'standard' week based on the planning experience of the planner. In reality a 'standard' week rarely occurs, due to the absence of the right surgeon at the right time amongst others. The tactical and operational planning are highly restricted due to the varying attendance of surgeons, same day consultations with other departments and fluctuating numbers of new patient arrivals. The planning method allows for OD-blocks with only new or recurrent patients, where new patient blocks are perceived more stressful. Furthermore, consultation slot types are changed from recurrent to new patient to accommodate for fluctuating numbers of new patient arrivals. The current planning method tries to cope with restrictions and new patient arrivals, but may result in peaks in the number of new patients per block and week and lead to heavy fluctuations in perceived workload at the outpatient department.

OK versus KLOK versus POK

Some surgeons perform surgeries in the OK or KLOK that could have been performed in the POK, which is cheaper (LeBlanc et al., 2011) and still has a very low rate of post-surgery infections (LeBlanc et al., 2011). Surgeries in the POK require less administration, less moving of OK-supplies and patients have a less complicated process during their treatment. Surgeries are performed in the OK, KLOK or POK, depending on the preferred method of anesthetic and room requirements the surgeon has. However, surgeons have various preferences. This may cause a patient to have a treatment for carpal tunnel syndrome (CTS) at the OK for their left hand and at the POK for their right hand, which causes confusion for the patient. It suggests that at least one of the processes is inefficient. Furthermore, planning OK- and KLOK-blocks is more restricted because they are planned at least three months ahead and POK-blocks two weeks. The departments' management wants as many surgeries as possible to be performed at the POK for all aforementioned reasons and free up time at the OK.

Perturbations from surgeon's absence

The planning method, variability in new patient arrivals and surgeons planning restrictions make it difficult to manage patient flow and allocate the surgeon to servers to manage workloads. The planner finds it particularly difficult to mitigate the perturbations from the surgeon absence of one week or more. Surgeon's holidays, for example, may cause higher access times for patients, which means patients must wait longer for a consultation or surgery. The current blueprint schedule does not solve these issues.

1.3 Research goal

We define the goal of this research as such:

To develop prospectively validated recommendations for the plastic surgery department to balance workloads and optimise flow.

The recommendations should enable the department to balance workloads for plastic surgeons, nurses and secretaries and aim for access times for patients complying with national guidelines. Furthermore, perturbations by the surgeon's absence should be minimised.

1.4 Research questions

To achieve the research goal, we state the following research questions:

1. *Which processes involve plastic surgeons, nurses, and secretaries and what are their performances as a result of the current planning method?*
   The perceived problems of the plastic surgery department may be the result of natural and artificial variability and planning method. In Chapter 2 we explain the current processes, resource control mechanisms and performances of the department in terms of Key Performance Indicators (KPIs). We identify root causes of the perceived problems.

2. *Which strategies and methods are available in literature to analyse the plastic surgery department and to develop planning method recommendations?*
   Chapter 3 identifies potential solutions to the root causes of the problems in the plastic surgery department by performing a literature review and consulting stakeholders.
3. *How can we model a plastic surgery outpatient department, and how can we balance workloads?*
   The situation of the outpatient department from Chapter 2 is combined with solutions from Chapter 3 to develop a model that reflects the performance of an outpatient department in reality. Chapter 4 presents the resulting model.
4. *What is the expected performance of proposed solutions compared to the current situation?*
   Experiments on the model from Chapter 4 show what interventions improve the situation of the outpatient department. Chapter 5 presents and discusses the results from experiments.
5. *What solutions should be implemented?*
   Recommendations for implementing the interventions from Chapter 5 are presented in Chapter 6.

2 Context analysis

This chapter explains the situation within the plastic surgery department. Section 2.1 describes the outpatient department, the processes patients go through and the differences between the OK, KLOK and POK. Section 2.2 explains the current planning method for blocks, consultations, and surgeries at the strategic, tactical, and operational level. The current performances of the outpatient department as well as new patient arrivals, access times and variability of access times are presented in Section 2.3. Section 2.4 concludes the context analysis by demarking the problem of the department.

2.1 Process descriptions

This section describes the outline of the outpatient department, the processes that patients experience and the differences between the OK, KLOK and POK.

2.1.1 Outpatient department outline

The outpatient department consists of the front desk, examination rooms, the POK and the back-office. Surgeries at the OK and KLOK take place at the OR-complex of the hospital. Four plastic surgeons, four nurses, six secretaries and one manager work at the outpatient department. Surgeons have consultations with new and recurrent patients. Nurses only have consultations with recurrent patients. During nurses' consultation blocks, a hand therapist is present between 8.30 AM and 10.00 AM.

2.1.2 New patient arrivals

Patients are mostly referred to the plastic surgery department by general practitioners and the neurology department of DZ. General practitioners refer patients to the plastic surgery department for one of two consultation types: a general new patient consultation or a specialised consultation for medically complicated hand diagnostics (Hand Diagnostics Centre, HDC). Consultations at the HDC are always same day consultations with a hand therapist. The neurology department refers to the plastic surgery department via the Carpal Tunnel Syndrome (CTS)-fast-lane, where a patient first has a consultation at the neurology department and is referred to the plastic surgery department when a certain threshold value results from an EMG-test. The consultation schedule at the HDC and via the CTS-fast-lane depends on agreements with other departments.

The number of new patient arrivals at the outpatient department at a weekly basis varies between 5 and 75 in 2017, 2018 and 2019. The average number is 48 patients. Figure 2 shows a typical year for the number of weekly arrivals. No clear seasonal pattern can be seen.

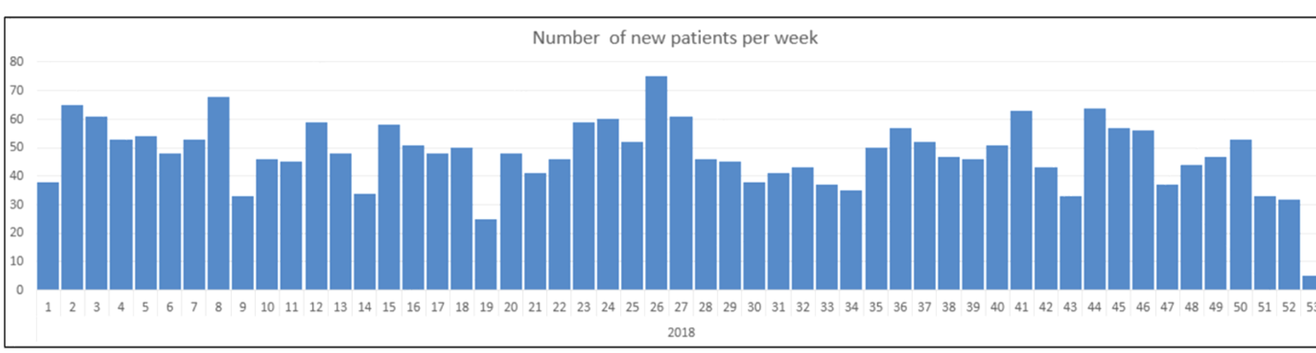


Figure 2 - Number of new patients per week in a typical year (n=2534, 2018, HiX)

The perceived working pressure is higher for consultations with new patients than for recurring patients: the workload for secretaries is higher because most patients need an appointment for another consultation or surgery after a first consultation. The workload for surgeons is higher because new patients need a more detailed explanation about procedures. The workloads increases when new patient appointments are bundled.

2.1.3 Patient care pathways

We define access time as the number of calendar days from the moment a consultations or surgery is planned until the day of consultation or surgery itself. Access times apply to every consultation in the outpatient department, except in the CTS-fast-lane. Access times apply to all surgeries in the OK, KLOK and POK.

After arriving at the plastic surgery department as new patient, the patient has five options (see Figure 3):

1. After some days, the patient returns at the outpatient department for another consultation as a recurring patient with the same surgeon or a nurse.
2. The patient is scheduled for surgery at the OK.
3. The patient is scheduled for surgery at the KLOK.
4. The patient is scheduled for surgery at the POK.
5. The patient is discharged.

After surgery at the OK, KLOK or POK, the patient always has a consultation as a recurring patient with a nurse or surgeon within 10 to 14 days. The patient can have multiple CP consultations before being discharged.

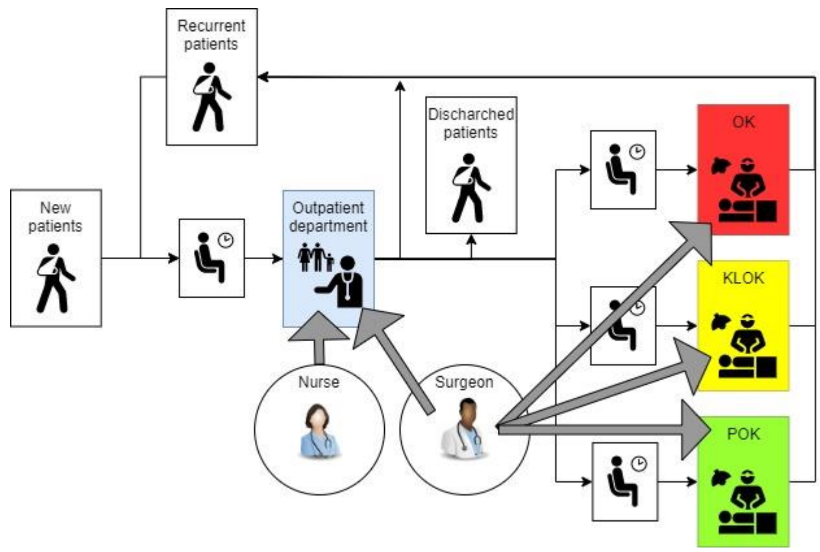


Figure 3 – Schematic view of patient care pathways

2.1.4 OK, KLOK and POK

This subsection explains the difference between the OK, KLOK and POK and gives the ten most performed surgeries to provide a reference for other plastic surgery departments.

Medically complicated surgeries are performed at the OK with an anesthetist present. The OK is fitted to meet the highest air and hygiene standards. Patients are present at the hospital for some hours or an entire day for surgery in the OK because of the internal processes within the OR-complex.

The KLOK is situated at the border of the OR-complex and shares the highest air quality and hygiene standards with the OK. Patients do not need a long stay at the hospital because they use a waiting room outside of the OR-complex to wait for their surgery. Surgeries at the KLOK are less medically complicated, so no anesthetist is required for surgeries.

The POK is situated at the OD. The surgeries at the POK require lower air quality and hygiene standards and no anesthetist. The waiting room of the OD is used for the POK patients.

Figure 4 presents the ten most performed surgeries at the OK and KLOK and the total number of surgeries in 2017, 2018 and 2019. Figure 5 presents the ten most performed surgeries at the POK and the total number of surgeries in 2017, 2018 and 2019.

Surgery	Year 2017	2018	2019
Neurolysis with microscoop	183	200	157
Surgically removing lump from cutis, subcutis etc.	70	69	67
Dermatography	39	50	58
Surgical A1-pulley release	32	19	47
Surgical treatment of constriction of dupuytren by means of excision of the fascia palmaris	30	56	41
Radiant excision of fascia palmaris	62	42	33
Tenolysis flexor finger or palm	28	44	30
Plastic correction of breast deformity	28	36	24
Surgical treatment of carpal tunnel syndrome, open procedure	31	32	17
Surgical removal of lump, corpora aliena etc.	33	46	17
Other	392	364	324
Total	**928**	**958**	**815**

Figure 4 - Top ten of numbers of surgeries at the OK and KLOK per year (HiX)

Surgery	Year 2017	2018	2019
Surgical treatment of carpal tunnel syndrom	149	216	259
Trigger finger release	78	103	132
Excision benigne tumors - FG	46	78	66
Surgical removal of ganglion	13	36	43
Excision benigne tumors - non-FG	15	18	23
Tenolysis	8	27	16
Maligne tumors - FG	7	12	14
Blepharoplasty	11	20	11
Dermatography	18	10	7
Selective fasciectomy	5	4	11
Other	40	58	47
Total	**390**	**582**	**629**

Figure 5 - Top ten frequencies of POK-surgeries per year (HiX)

2.2 Resources planning and control

This section explains how blocks, consultations and surgeries are planned. The plastic surgery department registers the attendance of surgeons, nurses, and secretaries in an Excel sheet. The planning software in DZ is HiX 6.2 Standard Content.

2.2.1 Capacity dimensioning at the strategic level

On a yearly basis, the plastic surgery department of DZ agrees with health insurers how many patients it must help with consultations and surgeries. Updated agreements are compared to last year's performance and capacity is adjusted accordingly.

2.2.2 Planning at the tactical level

To process the agreed number of consultations and surgeries the department plans blocks at the OD, OK, KLOK and POK at the tactical level. While all secretaries schedule surgeries and consultations, one secretary acts as planner and is responsible for planning blocks in the outpatient department for surgeons and nurses, requesting OK- and KLOK-blocks and planning POK-blocks for surgeries.

The planner uses a blueprint for a standard week with OK-blocks, KLOK-blocks, POK-blocks, and consultation blocks at the OD for each surgeon. The blueprint in Table 1 shows where each surgeon works (OD, OK, KLOK or POK) and for which consultation type (NP, CP, HDC and CTS). Note that there are OD-blocks with only NP-consultations, where NP-consultations are perceived as more stressful.

The planner first allocates surgeons and nurses to the OK and KLOK, then to the POK, and subsequently to the OD.

Table 1 - Blueprint schedule for planning. Blocks for the OK are in red, KLOK in yellow, POK in green and OD in blue

	Monday		Tuesday		Wednesday		Thursday		Friday	
	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon
Surgeon A	OD - NP and CP	OD - NP	Other	Other	1/2 of weeks OD - NP and CP	1/2 of weeks POK	OD - NP and CP	3/4 of weeks OD - NP	5/6 of weeks OK	5/6 of weeks OK
		HDC			1/2 of weeks home	1/2 of weeks home	CTS	1/4 of weeks POK	1/6 of weeks OD - NP and CP	1/6 of weeks OD - NP and CP
Surgeon B	OD - NP	OD - NP	1/2 of weeks OD - NP and CTS	1/2 of weeks OD - NP	OD - CP	POK				
	1/2 of weeks OK	1/2 of weeks OK	1/2 of weeks OK	1/2 of weeks OK	1/2 of weeks home	1/2 of weeks home				
Surgeon C	OD - NP	OD - NP							OD - CP	3/4 of weeks OD - NP
	1/2 of weeks OK	1/2 of weeks OK								1/4 of weeks KLOK
Surgeon D	OD - CP	OD - NP	1/2 of weeks OD - NP and CTS and HDC	POK			3/4 of weeks OK	3/4 of weeks OK		
			1/2 of weeks home	1/2 of weeks home						

Conventional operating room (OK) and small operating room (KLOK)

The planner requests OK blocks for the OK and KLOK three to four months ahead for a period of four or five weeks, as Table 2 shows. The planner requests OK-and KLOK-blocks depending on the future attendance of each surgeon, the waiting list for each surgeon and the filling of blocks that are already planned. The OK department decides which of the requested blocks are allocated to the plastic surgery department three months ahead, so planning surgeries is also possible up to three months in the future.

Table 2 - Timeline for planning blocks, surgeries, and consultations

	Week X	X + 1	X + 2	X + 3	X + 4	X + 5	X + 6	X + 7	X + 8	X + 9	X + 10	X + 11	X + 12	X + 13	X + 14	X + 15	X + 16	X + 17
OK-block	Allocated to plastic surgery department and planned														Requested			
KLOK-block	Allocated to plastic surgery department and planned														Requested			
POK-block	Planned		Planned depending on waiting lists and filling of sessions															
Surgery	Scheduled		Scheduling in available blocks															
Consultation	Scheduling in available blocks																	

Operating room in the outpatient department (POK)

Depending on the attendance of each surgeon and waiting lists for each surgeon, the secretary plans POK-blocks. Each POK-block requires one surgeon and two nurses. Because all nurses are interchangeable for their work at the plastic surgery department and the number of available nurses is never a restriction for planning, nurses' schedules are not taken into further consideration in this research.

Consultation blocks (OD)

Depending on the attendance of each surgeon, the secretary then allocates surgeons to consultations blocks in the outpatient department. First, the secretary schedules consultations blocks for the HDC and CTS-fast-lane. Next is the planning of consultation blocks for new patients and recurrent patients.

2.2.3 Scheduling at the operational level

Scheduling consultations and surgeries into the blocks happens at the operational level.

Surgeries

According to the secretaries, there is always room to schedule surgeries in the available blocks. In other words, there is no backlog of patients for surgeries waiting to be scheduled. Patients get appointments for surgeries in the OK or POK directly after a consultation at the front desk or by calling the back office.

As a principal rule, every patient has surgery with the same surgeon as he or she had a consultation with. In practice the average probability of having the same surgeon for the consultation and surgery is 95% based on 3680 operations in 2017, 2018 and 2019. Therefore, for the rest of this research we assume that the patient has the surgery with the same surgeon as the consultation.

Consultations

The department uses 16 codes for patient types in their planning system. Analysing the situation of the plastic surgery department only requires a division of consultation types into two types: NP and CP. The exact division is given in Appendix A.

Patients request consultations with a surgeon or nurse at the front desk or by calling the back office. They are scheduled immediately within three months in advance. In practice, the consultation type of a slot is changed frequently to fill a block or to have a short access time. A change of consultation type may increase the utilisation of a block, but also changes the ratio between new patients and recurrent patients per block. A problem with changing the type of slots is explained in Subsection 2.3.2.

2.3 Performances

This section presents the relevant parameters describing the perceived problems in terms of new patient arrivals, access times and variability of access times for the OD, OK, KLOK and POK. Furthermore, the ratio of weekly NP and CP consultations is discussed.

2.3.1 Access times

The outpatient department defined goals for access times according to Dutch national standards, called the "Treeknormen". We discuss if the outpatient department meets these goals for each subject separately. Additionally, we present the variabilities of access times because variability can significantly affect a processes' performance (Chand et al., 2009).

New patients

Treeknorm: 80% of new patients can visit the outpatient department for their first consultation within three weeks after contacting the OD. The maximum access time is four weeks. There is no access time for emergency care.

In 2017, 2018 and 2019 80% of new patients waited 32, 33 and 28 days respectively for their first consultation, so the norm is not met. Figure 6 shows an undesirable variability in the distribution of access times for new patients per surgeon.

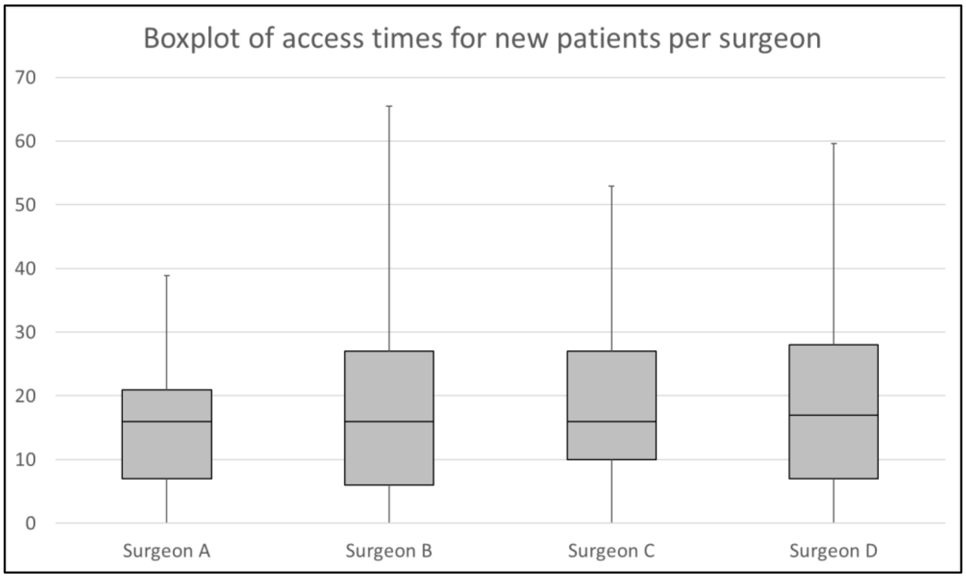


Figure 6 – Boxplot of access times in calendar days for new patients per surgeon (n=7474; 2017, 2018, 2019; HiX)

Treatments in the outpatient department and KLOK

Treeknorm: 80% of treatments in the outpatient department are performed within four weeks. This applies to surgeries at the POK. The maximum access time is six weeks.

Patients do not need hospitalisation for surgeries in the KLOK, therefore the same Treeknorm as for treatments in the POK applies. Table 3 shows that the average access times for all surgeons surpasses four weeks for the POK and KLOK. The norm is not met. The standard deviations are indicators for undesirable variabilities in access times.

Table 3 – Average access times and standard deviations for surgeries in the POK and KLOK (n=1597; 2017, 2018, 2019, HiX))

	POK		KLOK	
	Access time (days)	Standard deviation	Access time (days)	Standard deviation
Surgeon A	31,9	22,0	36,3	24,0
Surgeon B	39,2	28,0	38,5	27,8
Surgeon C	37,3	22,3	38,5	23,7
Surgeon D	34,6	24,0	39,5	27,7

Hospitalisations

Treeknorm: 80% of hospitalisations are done within five weeks. This applies for surgeries in the OK. The maximum access time is seven weeks.

Surgeries in the OK require a patient to be hospitalised. Figure 7 shows the average access time per week for the OK for all surgeons combined. The weeks with an average access time of zero all contain just one emergency surgery. 80% of the patients had surgery within access times of 59, 64 and 59 days in 2017, 2018 and 2019 respectively. Thus, the norm is not met. The average access time declines approaching the summer holidays while peaking around the end of a year. The rise is caused by the absence of surgeons combined with the reduction of OK blocks allocated to the plastic surgery department during the holidays.

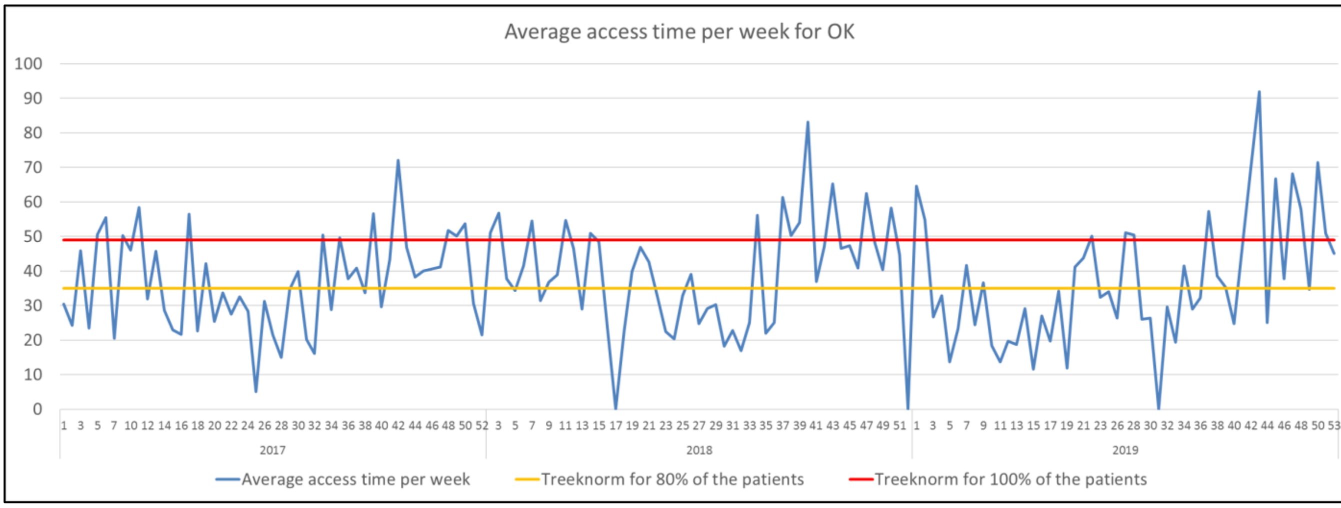


Figure 7 - Average access time in days for OK (n=2348; 2017, 2018, 2019; HiX)

2.3.2 NP – CP –ratio

Secretaries change the type of consultation slots depending on the number of new patients that request a consultation. Consequently, the number of new and recurring patients per surgeon varies across weeks as illustrated in Figure 8. A peak in the number of NPs causes a higher perceived workload. Furthermore, a peak in NPs in a particular week may cause a peak later on in the OK, KLOK and POK, and another peak after that in the outpatient department for CPs. A static NP-CP-ratio would expectantly reduce the variability in the workload for periods when a surgeon is available, however, a different NP-CP-ratio might be needed around weeks of absence. This suggests that there is an optimal NP-CP-ratio depending on the availability of each surgeon.

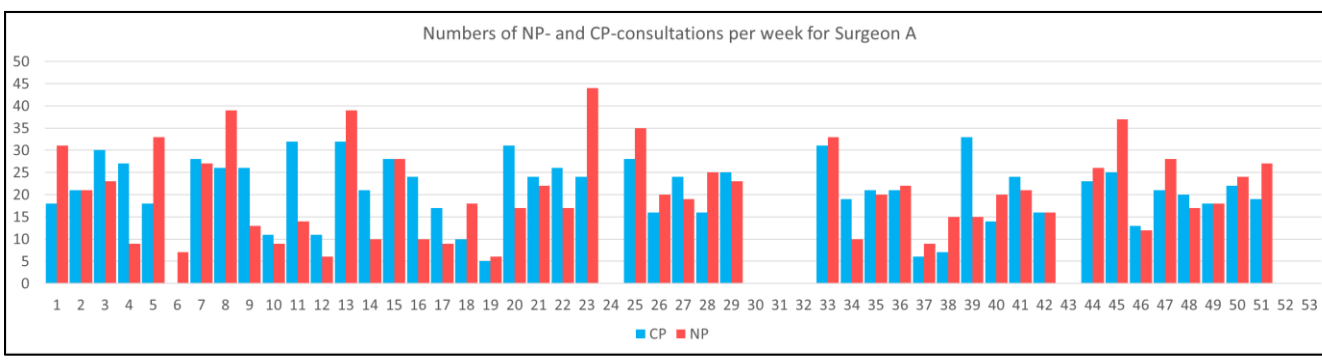


Figure 8 – Numbers of NP- and CP-consultations per week for surgeon A (n=1896, 2018; HiX)

Surgeons have the different historic NP-CP-ratios for two reasons:

1. Surgeons have specialisations, such as hand or breast specialists, where patients need different numbers of follow-up consultations.
2. Surgeons have different perspectives on how many follow-up consultations patients need with the same medical problem.

The optimal NP-CP-ratio may therefore differ between surgeons.

2.4 Synthesis and conclusion

This chapter answered Research question 1:

Which processes involve plastic surgeons, nurses, and secretaries and what are their performances as a result of the current planning method?

The current planning method tries to cope with the variability of arrivals of new patients and the planning restrictions of surgeons and patients. However, the method is unable to avoid variability in the number of new patient consultations, surgeries, and recurring patient consultations. The variability in the number of new patient consultations causes unevenly distributed workloads for surgeons, nurses and secretaries and causes access times to fluctuate and exceed norms.

Figure 9 depicts the causality of the problems in a problem cluster.

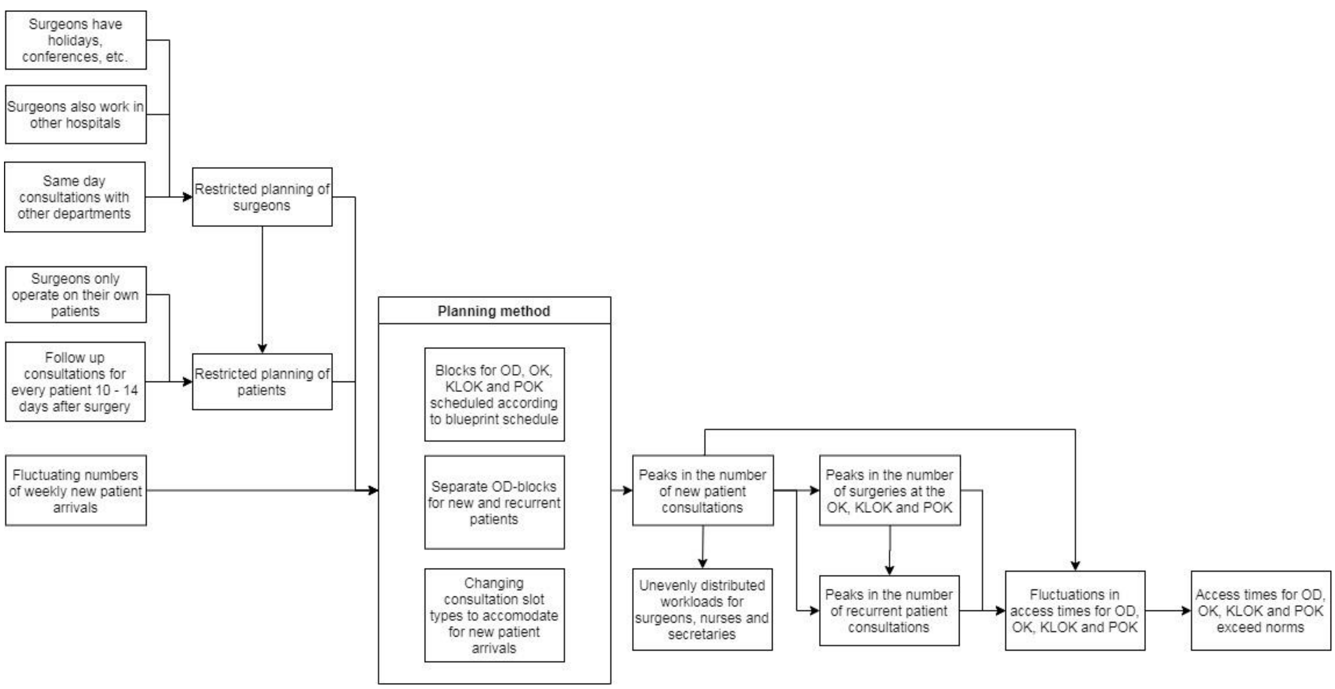


Figure 9 - Problem cluster

The department requires a tactical planning method that assigns blocks to surgeons, given their attendance. The planning method results in:

- The required NP-CP-ratio resulting in a more evenly distributed workload.
- Adherence to the Treeknormen.
- The agreed number of consultations and surgeries in a year.

The problem cluster is discussed with surgeons, nurses, secretaries, and the management of the plastic surgery department. They recognise the factors, problems, and their causality. Furthermore, they confirm their requirement for an adapted planning method including the mentioned properties. The rest of this study aims to make recommendations on the planning method.

Previous research may have identified (recommendations for) planning methods that apply to the context of DZ. Chapter 3 presents an analysis of existing planning methods in similar situations.

3 Literature research

In this chapter we consult the literature to assess existing studies into (models for) workload balancing in surgical hospital departments. Section 3.1 outlines the literature search approach. Section 3.2 discusses the relevant literature, and Section 3.3 summarises the insights we carry on to the remainder of this study.

3.1 Literature search approach

This section describes the process that is followed to find relevant literature.

As a first step we searched Google Scholar for articles relating to allocating surgeons to servers, minimising access times for patients and optimising utilisation. From the taxonomy of planning decisions in healthcare we learn that minimising patient's waiting time and maximising resource utilisation is the goal in appointment scheduling (Hulshof et al., 2012). However, appointment scheduling is not concerned with allocating surgeons to shifts. Staff-shift scheduling is, however, not concerned with access times and utilisation. Gunawan & Lau provide an adequate problem description for what they call the master physician scheduling problem:

" It is a planning problem of assigning physicians' full range of day-to-day duties (including surgery, clinics, scopes, calls, administration) to the defined time slots/shifts over a time horizon, incorporating a large number of constraints and complex physician preferences. The goals are to satisfy as many physicians' preferences and duty requirements as possible while ensuring optimum usage of available resources."

Having found a problem description, a list of all articles citing Gunawan & Lau was compiled. The list of 105 articles was searched with search string from Appendix B.

The search results in 13 articles of which two are reviews, being (Erhard et al., 2018) and (Abdalkareem et al., 2021).

Abdalkareem et al. review healthcare scheduling in an optimisation context. The objective of all scheduling systems in the optimisation aspect is to reduce the cost, patient waiting time and maximise resource efficiency. Articles are divided in five categories: Patient Admission Scheduling Problem, Nurse Rostering Problem, Operating Room Schedule, and Other Healthcare Scheduling And Planning Problems. The latter category receives less attention than others form researchers and physician scheduling is part of it. Methods for solving include mathematical programming and mixed integer linear programming. Regarding physician scheduling the writers conclude that big data analytic methods may improve data sets and other patient types than elective patients should be considered in models.

Erhard et al. divides the physician scheduling problem into three problem categories: Staffing, Rostering and Re-planning. Staffing problems involve strategic dimensioning and structuring of a workforce. Rostering involves creating concrete or generic shift rosters at the tactical or operational offline level. Re-planning involves short-term adjustments of a schedule on the operational online level. The goal of a problem can be financial, non-financial (for example minimising access times) or both. Furthermore, objective functions can have multiple (weighted) criteria. Solution approaches may be deterministic or stochastic in nature. The majority of literature uses deterministic mathematical programming modelling solutions like linear programming, integer programming and mixed integer programming, in exact or heuristic form. Less attention is given to variability in patient arrivals or service times. Simulation models evaluate problems where stochastic patterns are more realistic. Stochastic optimisation approaches derived from queueing theory could be merged with mixed integer programming techniques to generate improved scheduling models. Simulation models can evaluate schedules' quality and robustness, being less sensitive to unforeseen events and uncertainty.

3.2 Relevant literature

This section discusses relevant literature found by our structured search about physician scheduling, as well as some useful topic wise additions.

Physician scheduling problem

According to Erhard et al. (2018), the problem of the plastic surgery department in DZ is classified as a rostering problem with non-financial goals and with a stochastic demand for care. From the two aforementioned reviews on physician scheduling we mention the articles that describe a rostering problem with stochastic demand.

EL-Rifai et al. (2015) address the staff scheduling problem in an emergency department by optimising the shift distribution among staff and minimise the patients total expected waiting times. They propose a deterministic mixed integer model that is solved by a sample average approximation approach. Patient arrivals in the model and service times are stochastic. The resulting staff schedules are evaluated by a discrete-event simulation to verify the validity of assumptions and test robustness.

Badri & Hollingsworth (1993) describe an emergency department with a simulation model. Properties of their model were stochastic arrivals of patients and service times. A static schedule with the number of surgeons, nurses and beds that are allocated to each shift is evaluated by performance criteria that include resource utilisation, mean sojourn times, mean waiting times and numbers of patients at each resource. Multiple scenarios are evaluated, and a new admission policy was implemented by the hospital, reducing access and sojourn times.

Also focusing on an emergency department, Rossetti et al. (1999) apply a simulation model to test the effect of different assignment patterns for physicians on patients' throughput as well as the utilisation of required resources. In contrast to Badri & Hollingsworth (1993) the department has multiple wings where separate patient groups are treated, for example paediatrics, chest pain and minor emergency wings. Overall flow of patients was implemented in the simulation logic. The objective of the model is to minimise the total average patient time in the emergency department. Eighteen alternative solutions are evaluated, and hospital management is presented with a balancing decision: does the cost of decreased utilisation outweigh the benefits of shorter average sojourn times and reduces numbers of long sojourn times?

Although all studies evaluate an emergency department, all studies use simulation to evaluate a candidate schedule that minimises waiting time for patients and improve resource utilisation.

Tactical resource planning

Hulshof et al. (2016) describe a tactical plan to allocate a surgeon's time to different activities and control the number of patients that should be treated at each server to achieve equitable access times (Hulshof et al., 2016). Variability in new patient arrivals and resource capacity (like a surgeon's absence) have an impact on the network of servers that results in varying access times for patients and resource utilisations for hospitals (Hulshof et al., 2016). Their mixed integer linear programming model in an approximate dynamic programming approach considers these variabilities and stochastic patient transitions between servers. The model uses deterministic travelling times for patients between servers.

Spreadsheet simulation

Discrete-event simulation and Monte Carlo simulation can be performed by spreadsheet simulation in, for example, Excel (Law, 2014). Excel provides a random-number generator, summary statistics and graphical plots. Important challenges of simulation studies can be their inherent modelling complexity, coding requirements, costs, and training (Klein & Reinhardt, 2012). Limitations for spreadsheets include the availability of complex data structures, complex algorithm implementation, long execution times and data storage (Seila, 2005). However, Klein and Reinhardt (2012) simulate patient flows through the emergency department using spreadsheet simulation. Spreadsheet simulation is cheap, popular, powerful, and just as reliable as traditional software (Klein & Reinhardt, 2012). Included in their simulation model are uncertainty in arrivals, patient types, patient routing and treatment times using the rand()-function. The resulting length-of-stay statistics are compared with those from a traditional simulation platform and no significant differences are found. They conclude that spreadsheet simulations are as effective but cheaper, easier to understand and implement, and widely available.

3.3 Conclusion

In this chapter we answered Research question 2:

Which strategies and methods are available in literature to analyse the plastic surgery department and to develop planning method recommendations?

The problem as described in Chapter 2 is known in literature as the physician scheduling problem. The goal is to allocate physicians to shifts, while (in our case) minimising access times and optimising resource utilisation. Important properties for modelling the situation of the plastic surgery department of DZ are stochastic patient arrivals and stochastic patient flow from resource to resource.

Simulation approaches are more detailed with respect to the real-life situation compared to exact mathematical approaches. Also, simulation approaches have been shown to provide good solutions to physician scheduling problems. Therefore, we choose to develop a simulation model in this study to analyse our situation.

Chapter 4 describes the simulation model.

4 Model description

This chapter proposes a simulation model to evaluate the performance of interconnected servers for one surgeon. Furthermore, we propose an algorithmic approach to balance the workload for the surgeon by levelling the utilisations at each server. In this chapter we answer Research question 3:

How can we model a plastic surgery outpatient department, and how can we balance workloads?

Section 4.1 present the simulation model, while Section 4.2 and 4.3 respectively verify and validate the simulation model. Section 4.4 proposes a workload balancing algorithm and explains the interaction between the simulation and algorithm. Section 4.5 concludes this chapter.

4.1 Simulation model

In this section we propose a simulation model.

From Chapter 3 it is apparent a model with the following properties is required:

- A simulation model that evaluates a schedule of surgeons to shifts;
- In a spreadsheet program;
- With stochastic patient arrivals;
- With stochastic patient transitions between resources.

The model simulates a care chain process, for example as explained in Section 2.1.3 and Figure 3. The model reviews the situation of one surgeon at a time. The model's goal is evaluating an allocation of the surgeon to servers in terms of patient's access times and server utilisations. A detailed description of all inputs, key performance indicators (KPIs) and limitations of the simulation model are in this section.

Simulation model inputs

Definition:

- Block: One block is half of a working day, or daypart.
- Server type: server types are the outpatient department (OD), OK, KLOK and POK. Patients have consultations in the OD and surgeries in the OK, KLOK and POK.

Static inputs:

- Block Allocation Schedule (BAS): The surgeons schedule is the simulation's core. A BAS consists of 60 blocks: two blocks per working day, five working days per week and six weeks long. The BAS is six weeks long to allow for ample adjustment possibilities for a server's capacity, with steps of 1/60st per six weeks. The six-week cyclic BAS is repeated for all simulated weeks.
- Capacity per block: Depending on the server type the block has a certain capacity in minutes.
- Service times: Each consultation and surgery takes a number of minutes, called the service time. The service time in the outpatient department may differ for new and recurring patients.
- Holiday weeks: The set of week numbers the surgeon is absent, so there is no capacity.

Inputs with stochastic properties:

- New patient arrivals: On a daily basis new patients arrive at the outpatient department according to a probability distribution determined from historic data from 2017, 2018 and 2019. New patients are placed in the first free place where an outpatient block is on the schedule (First Come First Served), starting the day after arrival.

- Other patient arrivals: Historic data from 2017, 2018 and 2019 show some arrivals at other servers than the outpatient department who didn't have a new patient consultation first. This might happen when patients have an emergency surgery or had a new patient consultation with another surgeon. We determined the monthly number of recurring patients at every server (other than the outpatient department) as inputs for the simulation. These "other patient arrivals" happen in the same way as new patient arrivals.
- Transition probabilities: After a patient's consultation or surgery a probability exist for the patient to move to another server. These transition probabilities are determined from historic data from 2017, 2018 and 2019. Transitioned patients are placed in the first free place on the schedule starting the day after the consultation or surgery.

Key Performance Indicators (KPIs)

- Utilisation: The utilisation is calculated by dividing the used time with the capacity. The utilisation is determined per server.
- Access time: The number of calendar days between the patient's arrival and the first free place at the correct server in the schedule is the access time. The access time is recorded per server and patient type.
- NP-CP-ratio: The NP-CP-ratio is determined by the following equation and only applicable for the outpatient department:

$$NP - CP - ratio = \frac{Number\ of\ new\ patients}{Number\ of\ new\ patient + number\ of\ recurring\ patients}$$

Properties and limitations of the simulation model

- The simulation schedules patients in a First Come First Served manner. In reality the patients may have a preference for other dates, for example to postpone a surgery to or beyond holidays.
- In practice the access time for recurring patients is between 10 and 14 days, this is not integrated in the simulation model.
- New patients and recurring patients are mixed in the outpatient blocks.
- No-shows are not taken into account.
- Overtime is not possible.
- The simulation model reviews the situation of one surgeon. When drawing conclusions about planning methods or rules one should consider the total OK-, POK- and KLOK-capacity for the plastic surgery department because, for example, not all surgeons may operate in the same room at the same time.

Monte Carlo simulation

The simulation model as described above runs for multiple independent replications with the same input values and the same BAS and therefore classifies as a Monte Carlo simulation. The KPIs from all replications are averaged to acquire statistical confidence.

4.2 Verification

This section explains how the simulation model is verified. Verification of the simulation model concerns itself with determining whether the simulation model from Section 4.1 is correctly translated into a computer program (Law, 2014). The pseudo code of the program with is in Appendix C. The program of the simulation model is verified with multiple techniques discussed here.

The computer program consists of multiple smaller functions, where each function is tested and debugged. A walkthrough of the program is performed. A variety of settings of the inputs is reviewed to determine if the outputs are reasonable. During programming, multiple so-called traces, watches, and breakpoints were used, as well as stepwise running through the program. Any encountered problem was fixed.

We conclude that the level of detail and workings of the simulation model are correctly translated from the model from Section 4.1 to a computer program for the purpose of this research.

4.3 Validation

This section explains how the model is validated. Validation is the process to determine whether a simulation model is an accurate representation of the real-life system, for the particular objectives of the study (Law, 2014).

4.3.1 Parameter validation

Several actions validate the simulation model, the input parameters and output data. Surgeons, nurses, secretaries, the planner, and operational manager explained the departments processes to enable proper modelling. Historic data from the department are used to determine the parameter data for the simulation model. Historic data includes appointment data from the outpatient department and surgery data from the OK, POK and KLOK. A surgeon and planner both agreed that the historic data represent the situation in practice and are suitable for the simulation model. The validated parameters are:

- the arrival distributions of new patients and recurring patients at each server;
- the average duration of OK-, POK and KLOK-surgeries;
- the average duration of NP- and CP-appointments in the outpatient department;
- the average number of patients in an outpatient, OK-, POK- and KLOK-block;
- the probability distributions for patients that move between servers or exit the department.

4.3.2 Results validation

"The most definitive test of a simulation model's validity is to establish that its output data closely resemble the output data that would be expected from the actual (proposed) system" (Law, 2014).

We compared the model with the real-life department by running an experiment of one year with realistic holidays. The typical holiday weeks for Surgeon A are: 1, 10, 30, 31, 32, 41, 52. The BAS of current practice from historical data is used. Table 4 shows the number of consultations and surgeries that result from the simulation model compared to historic data. The numbers are within the range from the minimum and maximum numbers that historically occurred, except for the number of recurring patients in the outpatient department. However, it follows the trend of the decreasing relative number of follow-up consultations patients need per new patient consultation. These results are evaluated with the planner and surgeon and found to be an adequate representation of real life.

Table 4 - Number of consultations (n=5605; 2017, 2018, 2019; HiX) and surgeries (n=1679; 2017, 2018, 2019; HiX) for Surgeon A; historic data versus modelled.

	OD-NP	OD-CP	OK	POK
2017	1028	1002	309	253
2018	944	952	240	336
2019	844	835	206	335
Modelled	910	795	216	300

Since the goal of this research is to make recommendations on balancing workloads, and since all parameter data and the number of consultations and surgeries are believed to be good representations of real life according to the planner and surgeon, we conclude the simulation model is an accurate representation of the real-life system, for the purpose of this research.

4.4 Workload balancing algorithm

This section describes an algorithmic approach for levelling the workload of the surgeon. The simulation model can be used in multiple ways, yet balancing the workload of the surgeon is the subject of this study. The perceived workload of the surgeon is expected to level when the utilisation at each server is (nearly) equal.

The Monte Carlo simulation calculates the performance of a BAS in terms of the average utilisation per server. The algorithm's purpose is to find a BAS with server utilisations as levelled as possible given a number of blocks assigned to the surgeon. The algorithm consists of the following steps:

1. Determine a starting BAS.
2. Run the Monte Carlo simulation.
3. Are all available blocks used? If so, stop the program and evaluate the results. Otherwise, go to step 4.
4. Determine which server has the highest average utilisation.
5. Add one block to the BAS to the server with the highest average utilisation (add two blocks if the server is the OK or KLOK, since they are scheduled for whole working days).
6. Go to step 2.

To clarify, Figure 10 presents the interactions between the local search algorithm and Monte Carlo simulation.

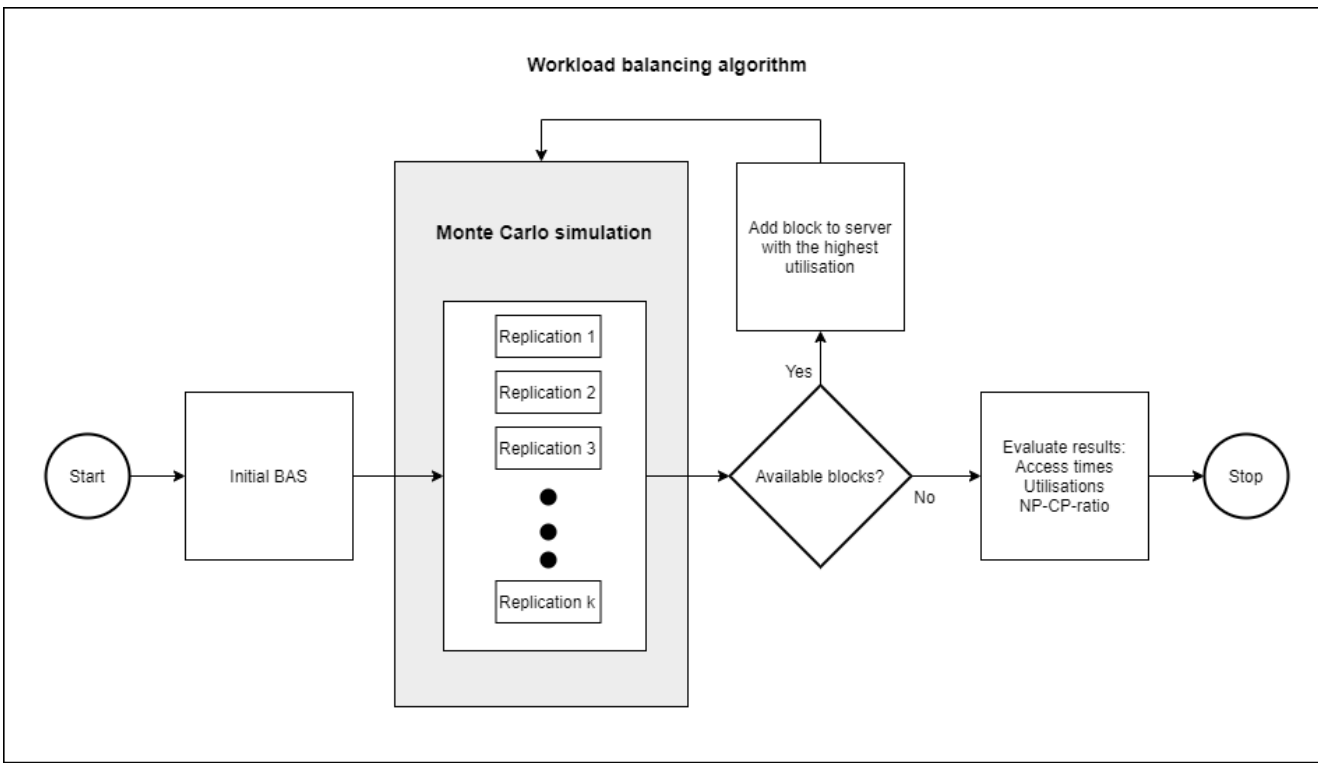


Figure 10 - Simplified interaction of the algorithm and simulation

4.5 Conclusion

In this chapter we answered Research question 3:

How can we model the plastic surgery outpatient department, and how can we balance workloads?

Combining literature, information from stakeholders and historic data results in the Monte Carlo simulation model and workload balancing algorithm as proposed here. The simulation model is verified and validated. The simulation model allows for experimenting with multiple BASs, while the workload balancing algorithm enables the efficient search for good solutions in terms of the KPIs. Chapter 5 presents trial runs, experimental design, and results from experiments.

5 Experiment results

Chapter 4 proposes a simulation model that represents the plastic surgery department's real-life processes. The model allows for experiments with the model, rather than experiments with adapted planning methods in real life. The model simulates the current situation and allows for evaluations of the current performance. Next, an adaptation to the planning is simulated and its performance evaluated. In this chapter we answer Research question 4:

What is the expected performance of proposed solutions compared to the current situation?

The simulation model simulates the care chain process for all four plastics surgeons separately, since 95% of the patients visit the same surgeon for all steps in the pathway. Without loss of generality, this chapter presents the results for Surgeon A to serve as an example for the experimental process. The inputs for Surgeon A are in Appendix D. Inputs may differs between surgeons.

We have programmed this in Excel VBA because of its availability, low cost, ease of use, good online support fora, and most hospital managers familiarity with it. Therefore, the program may be used in the future by departments similar to the plastic surgery department, in and outside DZ.

All necessary actions that result in reliable experiments are in Section 5.1. In Section 5.2 the experiments are described. Section 5.3 concludes this chapter.

5.1 Design of experiments

This section describes all requirements of a simulation study enabling reliable experiments and results. Determining which factors have the greatest effect on a response is the major goal of experimental design in simulation (Law, 2014). We present how to perform the experiments and which parts of the output data are used for drawing statistically significant conclusions.

The experimental design consists of specifying the length of the warmup period (Subsection 5.1.1), the length of each simulation run (Subsection 5.1.2), and the number of independent simulation runs (Subsection 5.1.3). Next, we present an overview of the experiments (Subsection 5.1.4).

5.1.1 Warmup period

When a simulation starts no patients are present at any server. On Week one, Day one, patients start to enter the system and have certain probabilities to get send to other servers. It takes (simulated) weeks for the model to come to a state where the number of patients at each server is a good representation of real life. The number of weeks it takes for the model to reach this state is called the warmup period and provides little relevant information, and is therefore discarded from the results of the experiments. Figure 11 presents an example of the warmup period in the average utilisation up to week w for Surgeon A.

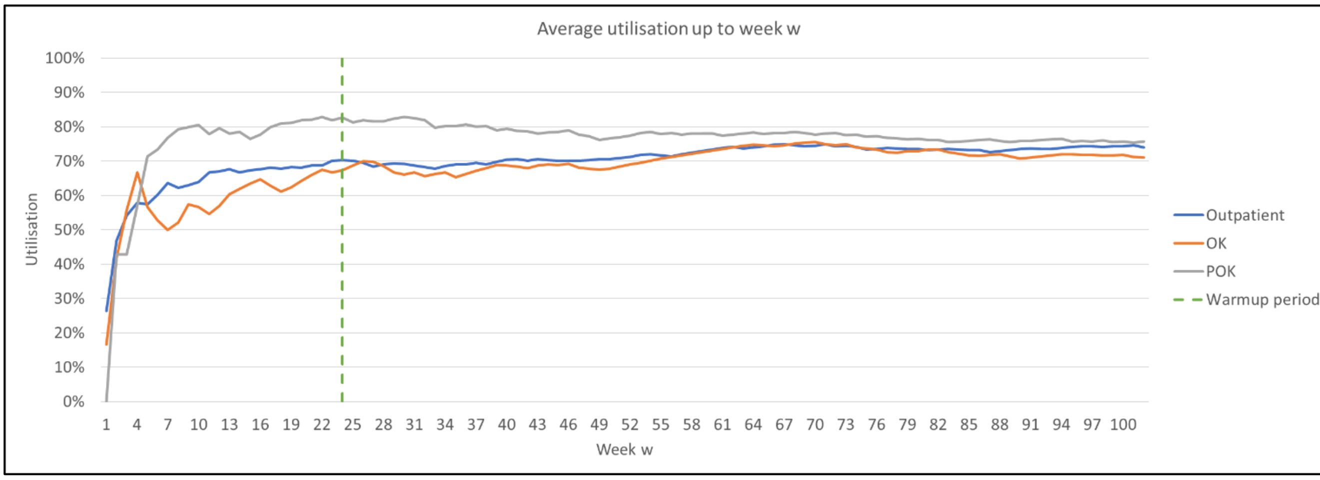


Figure 11 - Warmup period and remaining data example

The graphical procedure of Welch determines the warmup period for all KPIs for the surgeon and may differ between surgeons. Table 5 presents the warmup periods for Surgeon A:

Table 5 - Warmup period for Surgeon A as a result of Welch's graphical procedure: the number of weeks it takes the model to reach a steady state, per KPI.

Server	Patienttype	Total # appointments	Average access time per patient	Week NP-CP-ratio	Utilisation
Outpatient	New patient	14 weeks	20 weeks	21 weeks	n.a.
Outpatient	Recurring patient	17 weeks	20 weeks	n.a.	18 weeks
OK	New patient	n.a.	n.a.	n.a.	n.a.
OK	Recurring patient	19 weeks	19 weeks	n.a.	19 weeks
POK	New patient	n.a.	n.a.	n.a.	n.a.
POK	Recurring patient	21 weeks	21 weeks	n.a.	21 weeks
KLOK	New patient	n.a.	n.a.	n.a.	n.a.
KLOK	Recurring patient	n.a.	n.a.	n.a.	n.a.

The maximum number of weeks is 21. Because the pilot runs used for determining the warmup period are subject to randomness in the inputs and some subjectiveness (Law, 2014), the warmup period we use for production runs is rounded up. Because our input is a six-week BAS, we choose the period of discarded data for Surgeon A to be 24 weeks.

5.1.2 Length of each simulation run

With the warmup period of the first 24 weeks removed, the data in the remaining weeks presents the steady state of the real-life system (see Figure 11; data after warmup period). In a non-terminating simulation, the length of one run is determined by the duration at which enough time has passed to estimate the KPIs. In Excel static data cannot be larger than 64K (*Static Data*, 2017). Consequently, the maximum number of weeks in one simulation run is 102 for our model. Because it cannot be more and we do not want less, we choose 102 weeks as the length for each simulation run.

5.1.3 Number of replications

Just running the simulation model once and removing the warmup period would provide little statistical confidence in the average behaviour of system. This is due to the stochastic nature of some of the inputs. To acquire reliable results from the model we repeatedly run the simulation, cut off data from the warmup period, and average the remaining data over the replications. This is called the replication/deletion approach (Law, 2014).

The replication/deletion approach replicates multiple independent simulation runs where the warmup period is deleted and remaining data estimates mean values and confidence intervals for the utilisation, access times and the NP-CP-ratio. When the number of replications increases, the confidence interval shrinks, resulting in more precise estimations of the true mean. We determine the number of replications such that the confidence interval has a 95% probability to contain the true mean. For estimating the mean and confidence interval we refer to Law (2014).

Table 6 presents the minimal number of replications for a 95% probability that the true mean is contained in the confidence interval. Given these data, we choose to report values for KPIs while experimenting with 2500 replications.

Table 6 – Minimal number of replications per KPI for statistical confidence

NP-CP-ratio

Server	Number of replications
Outpatient	72

Utilisation

Server	Number of replications
Outpatient	86
OK	108
POK	95

Average waiting time

Server	PatientType	Number of replications
Outpatient	New patient	58
Outpatient	Recurring patient	358
OK	New patient	-
OK	Recurring patient	2475
POK	New patient	-
POK	Recurring patient	811

5.1.4 Overview of experiments

The experiments' goal is to find BASs that balance of the workload for the surgeon and provide insights in the behaviour of the department.

Experiment 1 determines the current performance and validates the simulation model.

Experiment 1a simulates the blueprint schedule and its performance. The blueprint schedule is in theory the surgeon's capacity. This simulation further validates the simulation model.

Experiment 1b simulates the BAS with the capacity from historic data and its performance. This enables us to identify performance improvements of candidate BASs. It also further validates the simulation model.

Experiment 2 finds a BAS with a balanced workload

Experiment 2 uses the simulation model and workload balancing algorithm to find a BAS that allocates the surgeon to servers at the same capacity the surgeon currently uses (from historic data). The goal is to find a BAS that balances the surgeon's workload by levelling the utilisations per server. Utilisations are compared to the current performance, known from Experiment 1a.

Experiment 3 evaluates the perturbations from the surgeon's absence.

Experiment 3a determines the perturbation of the surgeon's absence for one, two consecutive and three consecutive weeks for the BAS with the capacity from historic data. We evaluate the expected rise in utilisations and access times and how many weeks it takes for the system to reach a steady state again. This experiment enables us to identify performance improvements compared to Experiment 3b.

Experiment 3b determines the perturbation of the surgeon's absence for one, two consecutive and three consecutive weeks for the workload balanced BAS found in Experiment 2. We evaluate the expected rise in utilisations and waiting times and how many weeks it takes for the system to reach a steady state again. Furthermore, we compare the perturbation results with those from Experiment 3a.

5.2 Experiments

This section describes the experiments and results with the simulation model and workload balancing algorithm applied to the data of the plastic surgery department of DZ.

The simulation model with 2500 replications takes 13 minutes to complete on an Intel i5-4200 CPU @ 1.60 GHz, 8 Gb RAM and Microsoft Excel 365 version 2102.

5.2.1 Experiment 1a: blueprint schedule performance

The first experiment evaluates the current blueprint schedule from Table 1. Table 7, column "Blueprint schedule", displays the number of blocks per server in the six-week schedule for Surgeon A. The simulation repeats the schedule for a total of 102 weeks.

Table 7 - The number of blocks per server in a six-week schedule

	Blueprint schedule	Historic data
Outpatient	27	24
OK	10	12
POK	5	6
KLOK	0	0

A single simulation run (no replications) is performed. Figure 12 shows the resulting average access times up to week w. The simulation does not reach a steady state. Access times for the POK keep rising as a sign of a shortage of capacity. Figure 12 only displays a single run, however, the same patterns occurs while repeating the simulation.

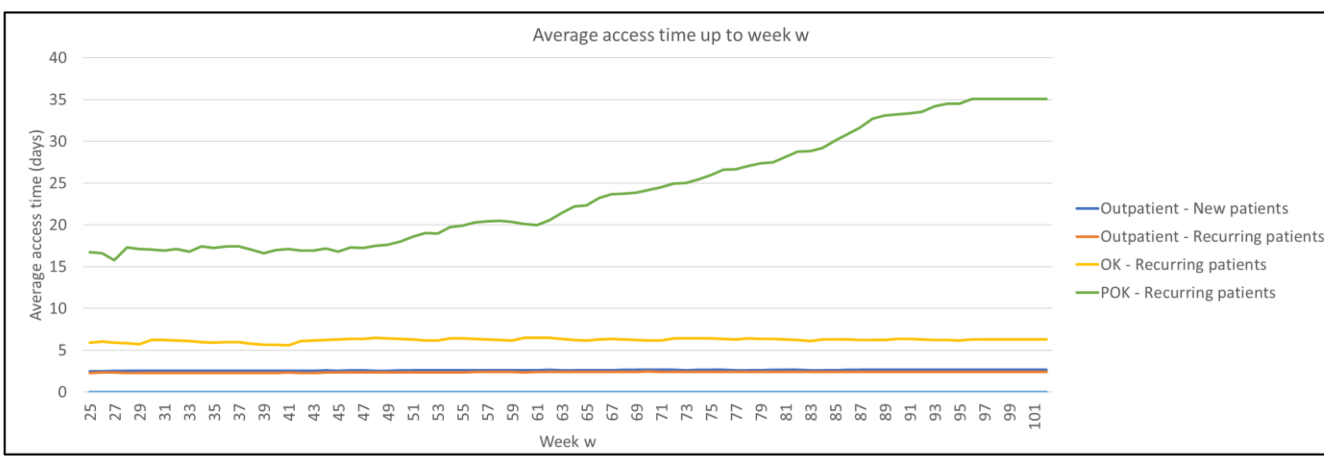


Figure 12 – Blueprint schedule; average access time up to week w for a single simulation run

The data implies that the current blueprint schedule cannot hold in practice, because it would cause patient's access times for the POK to go to infinity. Confronted with this data, the planner explains that when a rise in access times occurs, she plans extra sessions to compensate.

The experiment is repeated for 2500 replications to reach statistical confidence. The results are presented in Table 8, Table 9 and under column "current blueprint".
In the next experiment we use the capacity the surgeon uses according to historic data.

5.2.2 Experiment 1b: simulating the BAS with capacities from historic data

In historic data (2017, 2018 and 2019), Surgeon A had different capacities per server than the blueprint schedule (column "Historic data" in Table 7). In this experiment we determine the performance of the simulation model with the capacities from practice.

The results from a single run simulation in Figure 13 show that the simulation reaches a steady state and access times stabilise. Repeating the simulation has the same result. The experiment is repeated for 2500 replications to reach statistical confidence. The results are presented in Table 8, Table 9 and Table 10 under column "Historic data".

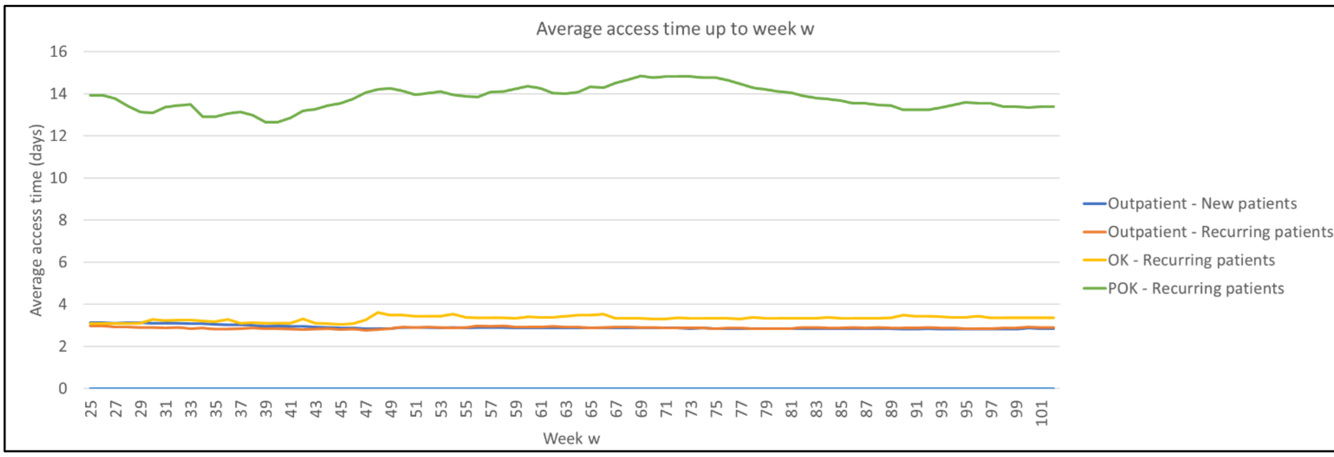


Figure 13 – BAS with capacity from historic data; average access time up to week w for a single simulation run

The results from Experiment 1a and 1b show that the blueprint schedule does not have enough capacity for the POK. In practice, planning extra sessions resolves the issue, which historic data confirms. The findings also validate the simulation model. Instead of using a BAS with too little POK capacity combined with extra planning activities, the department may use a new BAS with more POK capacity, as they do in practice.

5.2.3 Experiment 2: finding a BAS with a balanced workload

This experiment determines a BAS with a balanced workload by levelling the utilisation between servers. The workload balancing algorithm from Section 4.4 is applied. First, we determine a starting point and an end criterium for the algorithm. Second, we discuss results.

On determining a starting BAS for the workload balancing algorithm

As a starting point we use a BAS with 70% of the historic data capacity. Historically a BAS contains 42 blocks. 70% of 42 is around 29 blocks. We allocate 29 blocks to servers in the same percentages as in historic data, namely 17 blocks to the outpatient department, 8 blocks to the OK and 4 blocks to the POK.

Stopping criterium for the algorithm: capacity from historic data

The algorithm stops when it used the same number of blocks as in historic data. The number of blocks that Surgeon A uses according to historic data is 42. The number of blocks in the BAS of the starting point is 29. That leaves 11 blocks to allocate iteratively by the algorithm.

Results

For each simulated BAS Table 8 presents the utilisation and access times per server. Simulation results from the blueprint schedule and historic data are presented for comparison purposes.

In Table 8 colours indicate the server type, where green is the outpatient department, red is the OK and blue is the POK. A more intense colour indicates a higher number in that row, excluding current blueprint and historic data results.

From the results we observe the following (see Table 8):

- The simulation does not reach a steady state up until the BAS "34 blocks" due to ever-rising access times. The OK access times are unstable up until BAS "33 blocks" and POK access times up until BAS "34 blocks".
- For each BAS the number of blocks that are actually used is calculated by the sum of the products of the respective utilisation and allocated blocks per server. For example, for the "34 blocks" BAS the number of blocks in use is (18 x 94,1%) + (10 x 84,1%) + (6 x 84,6%) = 30,4 blocks. This number is relatively constant from the "34 blocks" BAS upwards, indicating the network of servers has sufficient capacity with those BASs.
- The utilisations from the "Historic data" BAS deviate more from average (71,7% [OD]; 69,9% [OK]; 84,9% [POK]; 73,1% [average]) than the workload balanced BAS (73,5% [OD]; 70,9% [OK]; 74,1% [POK]; 72,9% [average]). The deviations from average multiplied with the number of blocks per server results in the weighted utilisation deviation, which is 142 percentage points for the "Historic data" BAS and 48 percentage points for the workload balanced BAS.
- The Treeknormen state that the maximum access times are 28 days for a new patient at the outpatient department, 49 days for the OK and 42 days for the POK. The Treeknormen are violated up until the "34 blocks" BAS.

5.2.4 Experiment 3a: perturbations to the current capacity BAS

This experiment simulates the perturbations of the surgeon's absence on the BAS from current practice. The simulation runs with the "Historic data" BAS with the surgeon absent for one, two subsequent and three subsequent weeks. Table 9 presents the results in terms of utilisations and access times. Additionally, the number of weeks it takes for the utilisations and access times per server to reach their normal steady state level is presented. Colours and colour intensities are the same as in Table 8. From the results we observe the following:

- Any number of weeks of the surgeon's absence increases the average utilisation of the POK above the level (>86,4%), which we know to be stable (<84,9%).
- The longer the absence, the higher the utilisation on all servers. This makes sense, since the same number of new patients arrive at the servers, regardless of the length of the surgeon's absence. When the same number of consultations and surgeries are performed in a smaller number of available working weeks, the utilisation in those weeks are higher.
- The longer the absence, the higher the access times are on all servers. This is in line with our expectations.

5.2.5 Experiment 3b: perturbations to the BAS with balanced workload

This experiment simulates the perturbation of the surgeon's absence on the BAS with balanced workload. The simulation is run with the "42 blocks" BAS with the surgeon absent for one, two subsequent and three subsequent weeks. Table 10 presents the results in terms of utilisations and access times. Additionally, the number of weeks it takes for the utilisations and access times per server to reach their normal steady state level is presented. Colours and colour intensities are the same as Table 8. From the results we observe the following:

- The longer the absence, the higher the utilisation on all servers.
- The number of weeks for the utilisations to normalise are shorter compared to the current practice, especially for the OK and POK. Table 11 presents the average reduction of the perturbation of the utilisation.
- The longer the absence, the higher the access times are on all servers. This is in line with our expectations.
- The number of weeks for the access times to normalise are comparable for the OD.
- The number of weeks for the access times to normalise are shorter compared to the current practice for the OK and POK. Table 11 presents the average reduction of the perturbation of the access times.

Table 8 – Experiment 2: results

			Current blueprint	Historic data	29 blocks	30 blocks	31 blocks	33 blocks	34 blocks	35 blocks	36 blocks	37 blocks	38 blocks	40 blocks	41 blocks	42 blocks
Blocks per 6 weeks		Outp. dept.	27	24	17	17	18	18	18	19	20	21	21	21	22	23
		OK	10	12	8	8	8	10	10	10	10	10	10	12	12	12
		POK	5	6	4	5	5	5	6	6	6	6	7	7	7	7
		KLOK														
		Total	42	42	29	30	31	33	34	35	36	37	38	40	41	42
Simulated steady state utilisation		Outp. dept.	63,6%	71,7%	97,3%	97,8%	93,4%	93,8%	94,1%	89,4%	84,9%	80,5%	80,5%	80,6%	77,4%	73,5%
		OK	84,1%	69,9%	97,3%	97,7%	98,1%	83,6%	84,1%	84,2%	84,2%	84,3%	84,3%	71,2%	71,0%	70,9%
		POK	Unstable	84,9%	100,0%	97,4%	97,7%	97,9%	84,6%	84,9%	84,8%	84,7%	74,3%	74,1%	73,9%	74,1%
		KLOK														
Number of blocks in use (by sumproduct)				30,7	28,3	29,3	29,5	30,1	30,4	30,5	30,5	30,4	30,5	30,7	30,7	30,6
Average utilisation				73,1%	97,7%	97,7%	95,3%	91,3%	89,5%	87,1%	84,7%	82,2%	80,4%	76,6%	75,0%	72,9%
Access times (calendar days)	Outp. dept.	New patient	2,6	2,8	9,1	10,0	5,6	5,9	6,2	4,2	3,5	3,2	3,2	3,3	3,1	2,8
	Outp. dept.	Recurring patient	2,6	3,3	14,6	16,3	8,7	10,0	10,2	6,0	4,3	3,9	4,0	4,2	3,8	3,3
	OK		14,4	7,5	64,1	67,1	81,4	17,3	17,9	20,4	19,6	21,2	21,2	10,6	11,2	10,7
	POK		Unstable	16,8	199,8	40,1	41,7	43,9	16,1	16,3	17,2	19,0	12,8	12,9	13,2	13,9
Average access times (calendar days)				7,6	71,9	33,4	34,4	19,3	12,6	11,7	11,1	11,8	10,3	7,8	7,8	7,7

Table 9 - Experiment 3a: results

			Current blueprint	Historic data	Historic data (1 week absence)	Historic data (2 weeks absence)	Historic data (3 weeks absence)
Blocks per 6 weeks		Outp. dept.	27	24	24	24	24
		OK	10	12	12	12	12
		POK	5	6	6	6	6
		KLOK					
		Total	42	42	42	42	42
Simulated steady state utilisation		Outp. dept.	63,6%	71,7%	72,5%	73,4%	75,2%
		OK	84,1%	69,9%	75,7%	77,5%	78,6%
		POK	Unstable	84,9%	86,4%	88,1%	89,7%
		KLOK					
Number of blocks in use (by sumproduct)				30,7	31,7	32,2	32,9
Average utilisation				73,1%	75,4%	76,7%	78,2%
Access times (calendar days)	Outp. dept.	New patient	2,6	2,8	3,0	3,3	4,2
	Outp. dept.	Recurring patient	2,6	3,3	3,3	3,7	4,8
	OK		14,4	7,5	16,7	18,2	21,4
	POK		Unstable	16,8	17,5	19,4	21,1
Average access times (calendar days)				7,6	10,1	11,1	12,9

	Historic data (1 week absence)	Historic data (2 weeks absence)	Historic data (3 weeks absence)
	24	24	24
	12	12	12
	6	6	6
	42	42	42
Number of weeks to normalise	16	9	11
	29	28	27
	22	22	28
Number of weeks to normalise	5	4	5
	3	3	5
	34	27	38
	5	16	27

Table 10 - Experiment 3b: results

			Current blueprint	Historic data	42 blocks	42 blocks (1 week absence)	42 blocks (2 weeks absence)	42 blocks (3 weeks absence)
Blocks per 6 weeks		Outp. dept.	27	24	23	23	23	23
		OK	10	12	12	12	12	12
		POK	5	6	7	7	7	7
		KLOK						
		Total	42	42	42	42	42	42
Simulated steady state utilisation		Outp. dept.	63,6%	71,7%	73,5%	74,6%	76,2%	77,8%
		OK	84,1%	69,9%	70,9%	72,3%	73,7%	75,1%
		POK	Unstable	84,9%	74,1%	75,2%	77,7%	79,0%
		KLOK						
Number of blocks in use (by sumproduct)				30,7	30,6	31,1	31,8	32,4
Average utilisation				73,1%	72,9%	74,0%	75,7%	77,2%
Access times (calendar days)	Outp. dept.	New patient	2,6	2,8	2,8	3,1	3,7	4,8
	Outp. dept.	Recurring patient	2,6	3,3	3,3	3,6	4,3	5,7
	OK		14,4	7,5	10,7	11,4	11,7	12,1
	POK		Unstable	16,8	13,9	14,2	16,9	17,2
Average access times (calendar days)				7,6	7,7	8,1	9,2	10,0

	42 blocks (1 week absence)	42 blocks (2 weeks absence)	42 blocks (3 weeks absence)
	23	23	23
	12	12	12
	7	7	7
	42	42	42
Number of weeks to normalise	2	10	12
	2	6	9
	2	6	11
Number of weeks to normalise	2	3	7
	2	3	7
	5	6	8
	4	6	9

Table 11 - Average reduction of the perturbation caused by the surgeon's absence

	Surgeons absence		
	One week	Two weeks	Three weeks
Average reduction of utilisation perturbations	91%	47%	39%
Average reduction of access times perturbations	50%	41%	16%

5.3 Conclusion

In this chapter we answered Research question 4:

What is the expected performance of proposed solutions compared to the current situation?

The BAS that the plastic surgery department uses in practice does not have enough POK capacity to keep access times under control. In practice, the planner mitigates increasing access times by increasing capacity, which historic data confirms. We found that a BAS needs at least 6 POK blocks to be stable.

The surgeon's workload can be balanced by levelling the utilisation between servers, with the same total capacity as used in historic data. Using less than 34 blocks in the BAS shows unstable behaviour. Furthermore, the access times comply with the Treeknormen when total capacity is above 33 blocks.

In contrast to the current BAS, the balanced workload BAS retains stable behaviour and acceptable utilisation for the POK when Surgeon A is absent for one, two or three weeks. The balanced workload BAS also shows lower effects on utilisations and access times.

Chapter 6 uses the results from this chapter to make recommendations for the department's planning method.

6 Conclusions and recommendations

In this chapter we answer Research question 5:

What solutions should be implemented?

Section 6.1 presents the conclusions from this study, while Section 6.2 gives recommendations for further research.

6.1 Conclusions

The department's current planning method tries to cope with the variability of arrivals of new patients and the planning restrictions of surgeons and patients. However, the method is unable to avoid variability in the number of new patient consultations, surgeries, and recurring patient consultations. The variability in the number of new patient consultations causes unevenly distributed workloads for surgeons, nurses and secretaries and causes access times to fluctuate and exceed norms. The department requires recommendations for their tactical planning method to evenly distribute workloads and comply with the Treeknormen.

A literature study was conducted and confirmed the problem to be a physician scheduling problem. It entails allocating physicians to shifts, while (in our case) minimising access times and optimising resource utilisation.

A discrete and static Monte Carlo simulation model was constructed in a spreadsheet program and a workload balancing algorithm was developed. Important stochastic properties were patient arrivals and patient flows from resource to resource.

The plastic surgery department was used as a case study to experiment with the Monte Carlo simulation and workload balancing algorithm. The experiments show that the department's blueprint schedule does not hold enough capacity to comply with access time norms. In real-life, the planner adds capacity to mitigate access times, which historic data confirms. To reduce the number of planning activities and patient rescheduling we recommend using a BAS with appropriate capacities. Using less than 34 blocks in the BAS shows unstable behaviour. Furthermore, the access times comply with the Treeknormen when total capacity is above 33 blocks.

The experiments show that a workload balanced BAS decreases the weighted utilisation deviation from 142 percentage points for the "Historic data" BAS to 48 percentage points for the workload balanced BAS. Access times for the workload balanced BAS are well below the Treeknormen. The workload balanced BAS reduces the perturbation from the surgeon's absence from 16% up to 91% on average. Therefore, we recommend the department uses the workload balanced BAS. Balancing the surgeon's workload by levelling the utilisations will expectantly balance the workloads for secretaries and nurses.

To recall, the research goal is:

To develop prospectively validated recommendations for the plastic surgery department to balance workloads and optimise flow.

We developed a recommendation for the minimal capacity BAS that results in stable behaviour and access times within the Treeknormen. Furthermore, a workload balanced BAS is recommended to balance workloads. The workload balanced BAS recovers from perturbations sooner than the current BAS, optimising flow. The workload balanced BAS enables compliance with the Treeknormen.

Contribution to science

To the best of our knowledge the physician scheduling problem was not solved with a Monte Carlo simulation study and workload balancing algorithm before this study. The context of this study was a surgical department. The scope of the research is the care chain process of the patient from the first to last appointment in the department.

Contribution to practice

As a result from the problem analysis in this study, the hospital already adjusted their outpatient department blocks to mixed blocks for new and recurrent patients. Scheduling mixed blocks is easier for the planner and scheduling patients in mixed blocks is easier for secretaries. Mixed blocks reduce peaks in the number of new patients and subsequently peaks in demand downstream. This resulted in lower perceived workloads for surgeons, secretaries, and the planner. Furthermore, mixed blocks are perceived to have less overtime. The workload balanced BAS allows the department to improve utilisations, comply with the Treeknormen and reduce the effects of absence perturbations even further.

6.2 Recommendations

We recommend experiments with less capacity. With the workload balanced, less peaks in demand must be accounted for, thereby lowering the need for capacity, and potentially leading to cost savings.

The BAS "34 blocks" stands out as a stable BAS with the lowest number of blocks that still ensures that the Treeknormen are met. Therefore, we advise to further research the BAS to see its implications at the operational level.

The proposed BAS is evaluated with validated inputs, for example, the distribution of new patient arrivals. If these inputs change, another BAS might be more suitable. We recommend revising the BAS when large input changes occur.

In this study simulations are performed with one surgeon. To evaluate the combined results for more surgeons the algorithm could be expanded. We recommend using our approach in a multi-surgeon setting, complying with norms for access times first and secondly balancing workloads by levelling utilisations amongst surgeons and servers. The expanded algorithm's purpose is to find a BAS for each surgeon where all access times comply with the Treeknormen and with server utilisations, and thus workloads, as levelled as possible. The algorithm consists of the following steps:

1. Determine a starting BAS for each surgeon. For example, determine the number of blocks per server to be 70% of historic data. The number of available blocks is the difference between 100% and 70% of historic capacity.
2. If this is the first run, run the Monte Carlo simulation for each surgeon. Otherwise, run the Monte Carlo simulation for the surgeon that has a new BAS.
3. Are all available blocks used? If so, stop the program and evaluate the results. Otherwise, go to step 4.
4. Determine which server among surgeons violates the access time the most, set by the norm for access times. In our case-study the Treeknormen apply. Add one block to the BAS to the server that violates the norm for access times (add two blocks if the server is the OK or KLOK, since they are scheduled for whole working days). Go to step 2. If no server violates the norm for access times, go to step 5.
5. Determine which server among surgeons has the highest average utilisation. Add one block to the BAS to the server with the highest average utilisation (add two blocks if the server is the OK or KLOK, since they are scheduled for whole working days). Go to step 2.

Optionally a capacity cap for a certain server may be used, for example when the OK only provides a limited number of blocks to the department. When the algorithm results in access times violations caused by the limited OK capacity, it is a good starting point for discussions with the OK capacity allocator.

The algorithm results in the BAS per surgeon that firstly complies with the access time norms and secondly balances the utilisations and therefore balances the workloads between surgeons and, for each surgeon, between servers.

Appendix A: Patient types

The consultation types are given in the table as "Patient type". Subsequently, the division to NP or CP is given. 50/50 means that 50% of the consultations is called NP and 50% is called CP because we assume that patient type to be divided that way.

Patient type	NP or CP
CP	CP
CPEIND	CP
CPHAND	CP
CPMAM	CP
CTS	NP
HANDEN	50/50
NP	NP
NPCTS	NP
NPHDC	NP
NPMAM	NP
SP	50/50
SPMAM	NP
TC	CP
TC-N	CP
TEL-N	CP
UIT	CP

Appendix B: Literature search string

[review OR survey AND "physician scheduling" AND access OR waiting AND utilisation OR utilization]

Appendix C: Simulation model pseudo code

Declare units and types
Week {1 to 102}
Day {1 to 5}
Block {1 to 10}
HolidayWeeks {set of weeks from Week}

$$\text{ServerType}\begin{cases} 0 = Surgeon\ doesn't\ work \\ 1 = Outpatient\ department \\ 2 = OK \\ 3 = POK \\ 4 = KLOK \end{cases}$$

$$\text{PatientType}\begin{cases} 1 = NewPatient \\ 2 = RecurringPatient \end{cases}$$

StartingAllocation {1 to 60} as ServerType
ArrivalDistribution(ServerType, PatientType)
TransitionProbability(ServerType, PatientType)
NumberOfReplications {depending on experiment}

Initialisation

```
'Make a BAS
For week = 1 to 102
        For block = 1 to 10
                Copy the ServerType from the StartingAllocation in all weeks
                Set the capacity in each block
                The capacity for weeks in HolidayWeeks is zero
        Next block
Next week
```

Single run simulation

```
For week = 1 to 60
        For day = 1 to 5
                For server = 1 to 4
                A random number and the ArrivalDistribution determine the number of patients that arrive at this
                server today

                Each arrived patient is placed in the next available slot at the appropriate server in the BAS,
                starting tomorrow

                Go through all planned patients for this day, a random number and the TransitionProbability
                determine what is the next ServerType for them. Plan them in the next available slot starting
                tomorrow. Patients with "zero" as the next ServerType are discharged

                Store access times per PatientType, the SumOfWaitingTimes, utilisation, the number of
                appointments or surgeries and the NP-CP-ratio

                Next server
        Next day
Next week
```

Monte Carlo simulation

```
For replications = 1 to NumberOfReplications
        Call Single run simulation
Next replication
```

Determine average access times, AverageSumOfWaitingTimes, utilisations, the number of appointments and surgeries and the NP-CP-ratio

Appendix D: Inputs simulation model (Surgeon A)

New patiënt arrivals probabilty distribution	
Number of new patients per day	Probabilty
0	0,110
1	0,133
2	0,164
3	0,160
4	0,115
5	0,107
6	0,070
7	0,055
8	0,035
9	0,022
10	0,014
11	0,012
12	0,003
13	0,000
14	0,000
15	0,001

Other patiënt arrivals	
Number of patients per month without NP	
CP	6
OK	1
POK	5
KLOK	0

	Probability that a patient moves from queue i to queue j				
naar (j)	NP	OK	CP	KLOK	POK
van (i)					
NP	0	0,12	0,25	0	0,18
OK	0	0,01	0,77	0	0,02
CP	0	0,11	0,32	0	0,06
KLOK	0	0	0	0	0
POK	0	0,001	0,25	0	0,06

	Service time (minutes)		BlockCapacity (minutes)
	New Patiënt	Recurring Patiënt	
Server 1: OD	20	10	180
Server 2: OR	-	47,4	271,3
Server 3: POK	-	16,7	117,2
Server 4: KLOK	-	-	-

Optional: holidayweeks
Fill in for which weeks a surgeon has zero capacity
One square per week (leave empty otherwise)
25
34
54
55
56
65
76

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