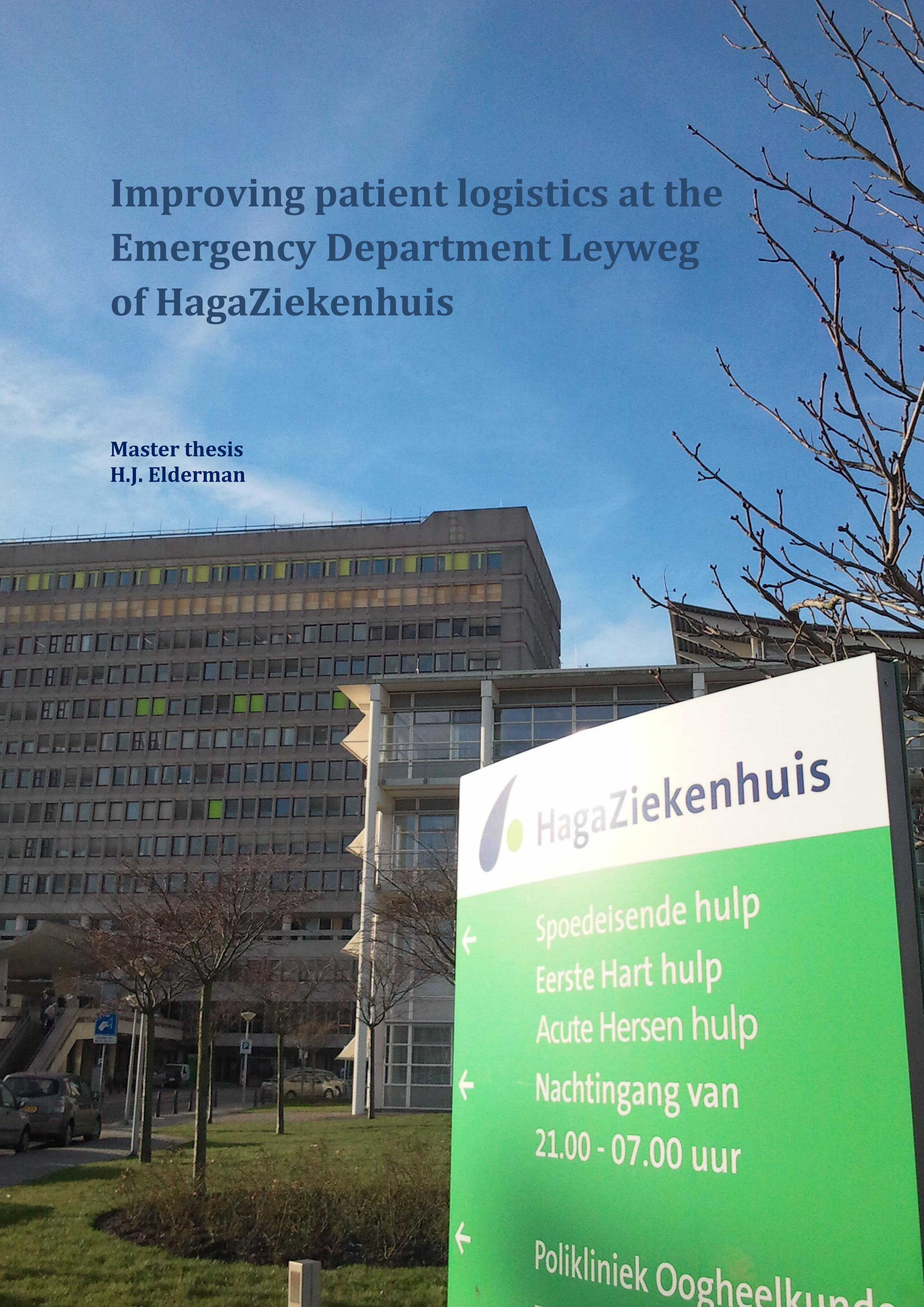
Improving patient logistics at the Emergency Department Leyweg of HagaZiekenhuis

Master thesis
H.J. Elderman



UNIVERSITY OF TWENTE.

HagaZiekenhuis

Improving patient logistics at the Emergency Department Leyweg of HagaZiekenhuis

A quantitative analysis to reduce waiting times

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Management summary

Motivation

The emergency department (ED) Leyweg of HagaZiekenhuis experiences problems with long waiting times, resulting in dissatisfaction among staff and patients. To deal with these problems, both management and staff desires quantitative insight in activity durations and waiting times, and would like to obtain suggestions for interventions to reduce the patients length of stay by reducing delays.

This research focuses on the four largest specialties, *general surgery, internal medince, cardiology, and neurology,* who together took care of 89.2% of all ED patients in 2010.

Objective and research questions

The objective of this research is twofold. The first objective is *to provide insight in the processes and delays of the emergency department*, and the second is *to recommend interventions to reduce the patient length of stay by reducing waiting times*. Four research questions are used to achieve these goals. The first research question is used to achieve the first objective, and the remaining three questions to achieve the second objective. The research questions are:

(RQ1) What are the EDs input, throughput and output patient flows, and what are the current activity durations and waiting times on the ED?

(RQ2) Which literature can we use to determine interventions?

(RQ3) Which interventions can we suggest to reduce waiting times and how can we assess them?

(RQ4) Which interventions do we recommend?

We provide a schematic overview of our research in Figure 1.

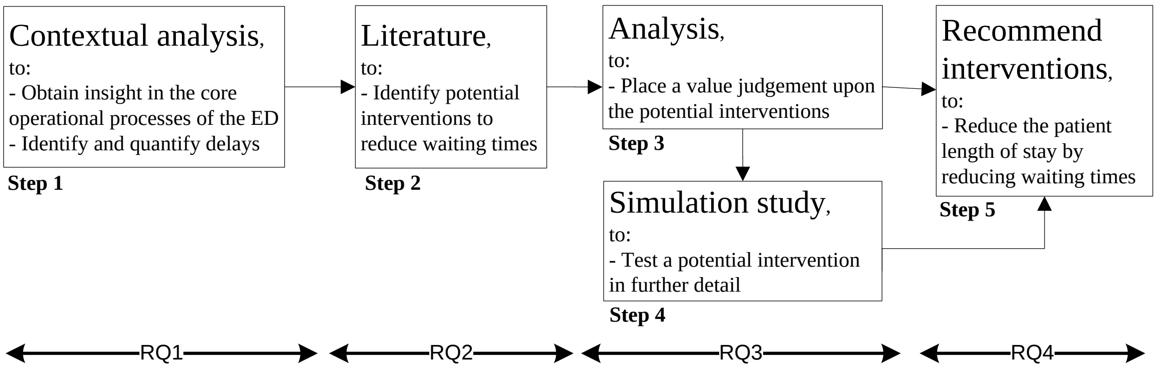


Figure 1: Schematic overview of research steps.

Methods

Six methods are used to answer the research questions. First, we used observations and interviews with residents, nurses, ED physicians, nurse practitioners, reception desk employees, and radiology technicians to get insight in the way the ED operates and their processes. Second, literature was searched and studied. We applied the *systems theory* to schematically map patient flows, and used principles of *lean manufacturing*, *factory physics*, and *capacity management*, to identify delaying factors and opportunities to reduce them. Third, we used the electronic patient records (EPRs) of all patients treated in 2010 to gather quantitative information on core logistical numbers, like patient volumes. But as the EPRs contain no data upon activity and waiting time durations, we also designed and executed a manual measurement. Using time registration forms filled in by nurses and residents, we measured activity and waiting times of all patients during a week. Furthermore, we used an analysis method in which the availability of staff is plotted against the number of patients present on the ED during different hours of the day. Unbalance between capacity and demand provide indications for opportunities for improvement, which in combination with the findings of the other research methods provided clear insights. And last but not least, we conducted a simulation study to test one of the identified *potential interventions to reduce waiting times* in detail.

Contextual results

In our contextual analysis we provide clear insights in the ED processes and allocation of resources, and identify twenty six delaying factors. Considering the delays, we determine that the delays caused by 'doctors not being available' and 'waiting time to laboratory tests results' are long delays that also affect many patients. Although these delays provide good opportunities to focus on with interventions, we decide that due to the high level of variability in the entire throughput process, the best results can be obtained by not only focusing on identifying interventions to reduce large delays, but for as many delays as possible. A small delay now, might cause a large delay later.

Interventions

With the insights from the literature, we identified sixteen promising interventions. We continued by dividing them in two groups based on whether we needed extensive additional research to assess them or not. The ten *suggested interventions <u>not</u> in need of extensive additional research* were all investigated and assessed, for which we used a combination of *costs*, *feasibility* ('the degree with which changes have to be made towards the EDs lay-out, ICT systems used, and in the way staff works'), and *intervention specific* pros and cons.

However, as we were limited by time, we were unable to also investigate all the six *suggested interventions in need of extensive additional research*. In consultation with an ED physician and the manager of the RVE acute care we identified the intervention of 'starting blood tests by the triage nurse' as the most promising, and investigated this intervention in detail using a simulation study.

Simulation results

We investigated the effects of our intervention 'starting blood tests by the triage nurse' using discrete event simulation. During our measurement we found that 77.1% of all blood tests are started by a nurse without interference of a doctor, however, currently the blood samples are only taken once a patient is placed inside a treatment room. We obtained the following results:

- the length of stay of patients whose blood test is started by the triage nurse (16% of all patients attending the ED between 07h30 and 23h15) decreases with an average of 9 minutes and 28 seconds;
- the average waiting time to triage increases with 1 minute and 25 seconds, from 7 minutes and 15 seconds to 8 minutes and 40 seconds, an increase that affects 72% of all patients attending the ED between 07h30 and 23h15. Although this increase seems low, the number of patients whose triage is not started within the 10 minute norm (NVSHV, 2008; Prins, 2011) increases from 23.9% to 28.7%, an increase of 4.8%;
- the number of patients treated in a hallway bed decreases with 13.1%.

It is up to the management team of the ED to decide whether they believe the increased waiting time to triage is acceptable, but we believe that especially the benefits of a 13% reduction in hallway beds outweighs the increase in waiting time to triage. And when we also include that the intervention is easy to implement, no costs have to be made, and the highest benefits are obtained during the moments in which time savings are most desired, namely the moments of crowding, we decide to recommend to adopt this intervention.

Recommendations

We recommend eleven interventions to be adopted by the ED, influencing fourteen of the twenty six delays. We recommend to: (1) start diagnostic blood tests by the triage nurse; (2) start a test pilot in which the working schedule of the residents of the internal medicine during weekdays is modified towards having one resident started at 12h00 instead of two at 08h30; (3) start a second test pilot in which an additional residents of the cardiology is scheduled in a new shift from 10h00 to 18h30 during weekdays; (4) residents must join co-assistants during their first patient visit; (5) place patients for the same specialty as much as possible in rooms near each other; (6) doctors should start a patients treatment also when they are near the end of their working shift; (7) send patients to the *acute assessment and diagnostic unit* directly after it is decided to admit the patient, instead of first completing the entire treatment at the ED; (8) start conversations with X-ray technicians to encourage them to retrieve the next patient when the X-ray room is idle, instead of waiting for the patient to be brought; (9) provide doctors with easy access to information on whether diagnostic test results are available, using strategically placed screens with status updates of diagnostic test results; (10) unused EPRs should automatically change to status ‘read only’; and (11) inform patients more actively by frequent short visits.

Further research

Alongside these recommended interventions, we also identified five promising opportunities to reduce delays even further, however, these opportunities first need to be additionally investigated on their actual effect, feasibility and costs. These opportunities are: (1) improve the accessibility of the outpatient clinic of the cardiology; (2) improve the accessibility of supervisors; (3) improve the response time of ambulances and cabs to transport patients to external facilities; and (4) digitize requests for X-rays, CT-scans and ultra sonogram, as well as (5) the process of finding an inpatient bed.

Management samenvatting

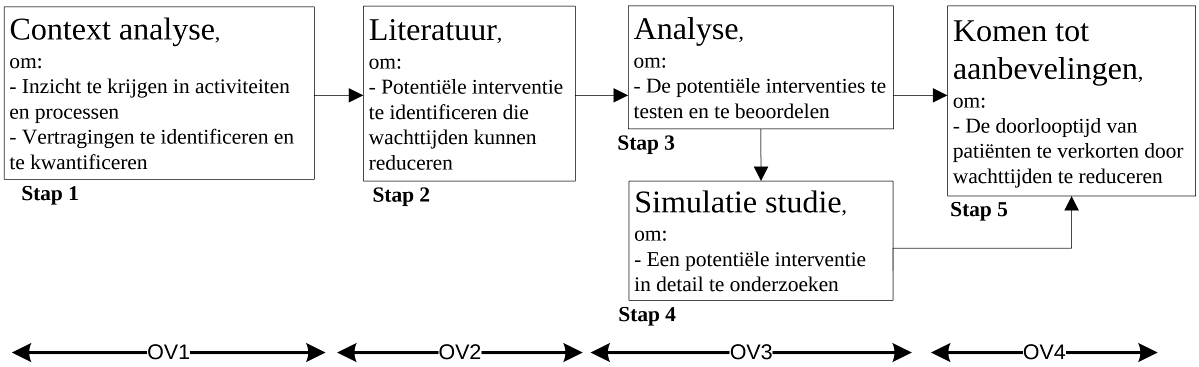
Aanleiding
De spoedeisende hulp (SEH) Leyweg van het HagaZiekenhuis kampt met lange wachttijden op haar afdeling, waardoor er ontevredenheid heerst onder patiënten en personeel. Om dit probleem aan te pakken, wensen zowel het management als de zorgverleners kwantitatief inzicht te krijgen in behandel- en wachttijden en willen zij ook graag aanbevelingen krijgen om de doorlooptijd van patiënten te verkorten door wachttijden te verminderen.

In dit onderzoek wordt gefocust op de patiënten en artsen van de vier grootste specialismen: *heelkunde*, *interne geneeskunde*, *cardiologie*, en de *neurologie*. Gezamenlijk behandelden zij 89.2% van alle patiënten op de SEH in 2010.

Doel en onderzoeksvragen
Het doel van dit onderzoek is tweeledig. Het eerste doel is *het verschaffen van inzicht in de processen en wachttijden op de SEH*, en het tweede doel is *het komen tot aanbevelingen om de doorlooptijd van patiënten te verkorten door wachttijden te reduceren.* Om deze doelen te behalen hebben wij vier onderzoeksvragen gehanteerd. De eerste onderzoeksvraag is gebruikt om het eerste doel te halen en de onderzoeksvragen 2, 3 en 4 zijn gebruikt om het tweede doel te behalen. De onderzoeksvragen zijn:

(OV1) Wat zijn de *input*, *throughput,* en *output* patiëntenstromen van de SEH, en wat zijn de huidige behandel- en wachttijden?
(OV2) Welke literatuur kunnen we gebruiken om interventies te identificeren?
(OV3) Welke interventies kunnen we overwegen om de wachttijden te reduceren en hoe kunnen we deze beoordelen?
(OV4) Welke interventies bevelen we aan?

In Figuur 1 geven we een overzicht van het onderzoek.



Figuur 1: Schematisch overzicht van de genomen onderzoeksstappen.

Methode
Om de onderzoeksvragen te beantwoorden hebben we zes methoden gehanteerd. Ten eerste hebben we SEH-artsen, verpleegkundigen, arts-assistenten, nurse practitioners, receptie medewerksters en röntgenlaboranten geobserveerd en geïnterviewd om inzicht te krijgen in de processen van de SEH. Ten tweede hebben we literatuur gezocht en bestudeerd. De *system theorie* is gebruikt om schematisch de patiëntenstromen in kaart te brengen, en we hebben inzichten van *lean*

manufacturing, factory physics, en *capaciteitsmanagement* gebruikt om vertragende factoren en interventies te identificeren. Ten derde hebben we gebruik gemaakt van de elektronische patiënten dossiers (EPDs) om logistieke gegevens te verkrijgen, zoals patiënten aantallen en aankomst- en vertrektijden. Daarnaast hebben we een tijdsmeting uitgevoerd om behandel- en wachttijden te achterhalen. Hiervoor hebben we eerst tijdsregistratie formulieren ontwikkeld, waarna deze gedurende een week voor alle patiënten op de SEH zijn ingevuld door verpleegkundige en artsen. Ook hebben we onderzocht of de inzet van artsen en verpleegkundige mogelijkheden biedt tot verbetering, waarbij we gebruik hebben gemaakt van een *vraag en aanbod analyse*. Afsluitend hebben we een simulatie studie uitgevoerd om één van de geïdentificeerde interventies in detail te onderzoeken.

Resultaten context analyse
De context analyse geeft duidelijk inzicht in de processen op de SEH en hoe middelen worden ingezet. Het resultaat van deze analyse is een overzicht van zesentwintig vertragende factoren. Van deze factoren zijn de vertragingen, veroorzaakt door 'artsen die niet beschikbaar zijn' en 'wachten op lab uitslagen' lang en deze treffen veel patiënten. Alhoewel deze vertragingen goed zijn om op te focussen, besluiten wij dat door de hoge mate van variabiliteit op de SEH het beste resultaat kan worden verkregen wanneer zoveel mogelijk vertragingen worden gereduceerd en niet alleen wordt gefocust op het identificeren van interventies om lange wachttijden weg te nemen. Een kleine vertraging nu, kan later namelijk leiden tot een grote vertraging.

Interventies
Met behulp van de literatuur hebben we zestien potentiële interventies geïdentificeerd, die we vervolgens hebben onderverdeeld in twee groepen op basis van het wel of niet nodig zijn van uitgebreid aanvullend onderzoek om de interventie te kunnen beoordelen. Alle tien *potentiële interventies waarvoor geen uitgebreid aanvullend onderzoek nodig was* hebben we onderzocht en beoordeeld, waarbij is gekeken naar gerelateerde *kosten*, *haalbaarheid* ('de mate waarin veranderingen moeten worden aangebracht in de lay-out van de SEH, ICT systemen, en in de werkmethoden van personeel') en *interventie specifieke* voor- en nadelen.

We konden echter, gelimiteerd door tijd, niet ook alle zes andere *potentiële interventies* onderzoeken. In samenspraak met een SEH arts en de manager van de acute zorg hebben we vervolgens de interventie 'de triage verpleegkundige dient bloedonderzoek te starten' als meest belovend geïdentificeerd, en deze gedetailleerd onderzocht met een simulatie studie.

Simulatie resultaten
Onze tijdsmeting onthulde dat 77.1% van alle bloedonderzoeken worden gestart op het initiatief van een verpleegkundige, zonder tussenkomst van een arts, maar momenteel wordt het bloedonderzoek pas gestart wanneer de patiënt in een kamer is geplaatst. Om de effecten van de interventie 'triage verpleegkundige dient bloed onderzoeken te starten' te onderzoeken hebben we gebruik gemaakt van *discrete event simulation.* De resultaten zijn:

- de verblijftijd van patiënten van wie het bloedonderzoek is gestart door de triage verpleegkundige (16% van alle patiënten die arriveren tussen 07h30 en 23h15) neemt af met gemiddeld 9 minuten en 28 seconden;

- de gemiddelde wachttijd tot triage stijgt 1 minuut en 25 seconden, van 7 minuten en 15 seconden naar 8 minuten en 40 seconden, een stijging die 72% van alle patiënten treft die arriveren tussen 23h15 en 07h30. Alhoewel deze stijging niet zo groot lijkt, veroorzaakt deze wel dat het aantal patiënten bij wie de triage niet wordt gestart binnen de 10 minuten norm (NVSHV, 2008; Prins, 2011) stijgt van 23.9% naar 28.7%, een stijging van 4.8%;
- het aantal patiënten behandeld in gangbedden daalt met 13.1%.

Het is aan het management team van de SEH om te besluiten of zij de toename in wachttijd tot triage acceptabel vinden, maar ons oordeel is dat met name de 13% reductie in het aantal gangbedden de toename in wachttijd tot triage overstemt. Verder zijn de voordelen van deze interventie het hoogst ten tijde van drukte, en kan de interventie eenvoudig en kosteloos worden geïmplementeerd. Concluderend bevelen wij aan om deze interventie te implementeren.

Aanbevelingen
Het eindresultaat van dit onderzoek zijn elf aanbevelingen om de wachttijden op de SEH te reduceren, die samen invloed hebben op veertien van de zesentwintig geïdentificeerde vertragende factoren. De aanbevelingen zijn: (1) de triage verpleegkundige dient bloedonderzoek te starten; (2) start een pilot waarin op doordeweekse dagen één arts-assistent van de interne geneeskunde begint om 12h00 in plaatst van twee om 08h30; (3) start een pilot met op doordeweekse dagen een extra arts-assistent voor de cardiologie, werkzaam in een nieuwe shift van 10h00 tot 18h30; (4) arts-assistenten dienen co-assistenten te vergezellen, elk keer als de co-assistent voor het eerst naar een nieuwe patiënt gaat; (5) patiënten voor hetzelfde specialisme dienen zoveel mogelijk in behandelkamers dicht bij elkaar te worden geplaatst; (6) artsen dienen de behandelingen van nieuwe patiënten ook tegen het eind van de dienst te starten; (7) de behandeling van patiënten waarvoor is besloten dat deze moeten worden opgenomen op de acute opname en diagnostiek (AODA) afdeling, dient op de AODA te worden voortgezet na dit besluit in plaats van eerst helemaal te worden afgerond op de SEH; (8) start gesprekken met de röntgenlaboranten, opdat zij patiënten zelf halen wanneer de röntgenkamer leeg is; (9) plaats strategisch geplaatste schermen waarop ‘real time’ wordt weergegeven of diagnostiek resultaten al beschikbaar zijn; (10) de status van ongebruikte EPDs dient automatisch te veranderen naar ‘read only’; en (11) artsen en verpleegkundigen dienen patiënten actiever te informeren door middel van frequente korte bezoeken.

Verder onderzoek
Wij identificeren vijf interessante mogelijkheden om de wachttijd verder te reduceren, maar deze moeten eerst aanvullend worden uitgedacht en onderzocht op *effecten*, *haalbaarheid* en *kosten*. De geïdentificeerde mogelijkheden zijn: (1) verbeter de toegankelijkheid van de polikliniek van de cardiologie; (2) verbeter de toegankelijkheid van superviserende artsen; (3) verkort de wachttijd op ambulances en lig taxi´s om patiënten te transporteren naar externe faciliteiten; (4) digitaliseer de aanvraag van röntgenfoto’s, CT-scans en echo’s, en (5) digitaliseer het zoekproces naar een ziekenhuisbed voor een patiënt die moet worden opgenomen.

Preface

This report contains my master thesis, conducted at the emergency department of HagaZiekenhuis. All involved people have learnt from this project, and I believe it provides a significant step forward in the process of improving the patient logistics at the emergency department. I thank everyone who helped and supported me during this research, as I could not have achieved this without them.

I thank Theresia van Essen, PhD student at HagaZiekenhuis, and Erwin Hans and Carine Doggen, both professor at the University Twente. Theresia, thank you for our discussions, your feedback on the many report drafts, and our informal conversations over lunch. I wish you the best with your PhD project! Erwin, I am grateful for our discussions and especially your support during crucial decisions upon how to structure my research. Carine, thank you for your feedback and willingness to participate in my graduation commission. Alongside my supervisors from the university, I also want to thank my supervisor at HagaZiekenhuis, Artze Prins, the manager of the RVE acute care. Artze, thank you for this opportunity to conduct my research at HagaZiekenhuis, but especially for your close involvement. Despite your busy schedule you always made time for me and supported me with your knowledge and experience.

Furthermore, I express my gratitude to all ED staff for their participation and involvement, with special thanks to Annemarie, Arjan, Maro, Suzanne and Ernst-Jan. I have felt very welcome at your department and enjoyed our conversations. I also thank my fellow students, Frank and Joël, for our discussions and cups of coffee, and last but not least my family and friends for all their support!

With this thesis, I finish my master in Industrial Engineering and Management at the University of Twente and my time of being a student. I am proud of what I have achieved, and excited about what the future will bring!

Erik Elderman
Den Haag, Februari 2012

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List of abbreviations

AADU	Acute admission and diagnostic unit
ECG	Electrocardiogram
ED	Emergency department
EPR	Electronic patient record
CT	Cycle time
CT-scan	Computed tomography scan
CV	Coefficient of variation
DF	Delaying factor
GP	General practitioner
IEP	Integrated emergency post
LOS	Length of stay
MTS	Manchester Triage System
NP	Nurse practitioner
TH	Throughput time
WIP	Work in progress

Chapter 1 Introduction

Emergency departments are challenged to provide rapid access to high quality care. Patients arrive through multiple channels and in different volumes over time (Hall et al., 2006). Also the acuity of their care needs varies, as well as the workload between individual patients (Ozcan, 2009). All these factors give managers a hard time to allocate the limited resources efficiently and match capacity with demand. When the available capacity does not meet demand, the available resources become overwhelmed, a phenomena in literature referred to as *overcrowding*. Literature shows that during these moments, waiting times increase, both patients and staff become dissatisfied, and patient safety is at risk (Fatovich, 2005; Hoot, 2008; Trzeciak S, 2003; Wiler, 2010).

Also the emergency department Leyweg of HagaZiekenhuis is facing problems. Each day a dedicated team of care providers and supporting staff works hard to provide all patients in their care need, but patients indicate dissatisfaction by long waiting times and staff gets frustrated by not being able to serve patients quickly. The major cause is believed to be the slow throughput of patients troughout the department, indicated by patients staying several hours at the ED. To deal with this problem both management and staff desires quantitative insight in the current situation, and suggestions for interventions to improve the patient flows in terms of reducing patient length of stay by reducing waiting times.

Chapter's structure

In Section 1.1, we start with a brief description of *HagaZiekenhuis* and the *emergency department Leyweg*. In Section 1.2, we formulate our research objectives, followed by our research motivation in Section 1.3. We end this chapter with a description of our research questions in Section 1.4, which we use to structure our research.

1.1 Background

HagaZiekenhuis

HagaZiekenhuis is a top clinical teaching hospital in the Netherlands. The hospital originated in 2004 by a merge of *Ziekenhuis Leyenburg* and *Stichting Samenwerkende Ziekenhuizen Juliana Kinderziekenhuis/ Rode Kruis Ziekenhuis*, and covers a care area of 300,000 civilians in The Hague region. In Table 1.1 we provide some core numbers of the HagaZiekenhuis.

Core numbers 2010	
Employees	3,763
Specialists	245
Beds	729
First outpatient clinical visits	209,500
Day treatment	28,808
Admissions	35,751
Average nursing days	5.2 days

Table 1.1: Core numbers HagaZiekenhuis.

Emergency departments

HagaZiekenhuis has two emergency departments, one located at the Leyweg and one located at the Sportlaan (later on we refer to these EDs as 'ED Leyweg' and 'ED Sportlaan' respectively). The ED

Leyweg functions as regional trauma center for adults, with a specialized *emergency cardiac care center*, an *emergency neurological care center*, and an *emergency eye center* for patients during evening, night and weekend hours. Approximately 40,700 patients attend the ED Leyweg a year (see Table 1.2), and 89.2% of all patients are treated by the doctors of the four largest specialties (see Figure 1.1). The ED Sportlaan is specialized in emergency pediatric care and is with approximate 27,000 patients a year the smallest of the two EDs (SAP, 2010).

2008	2009	2010
39,887	41,580	40,541

Table 1.2: Number of patients on ED Leyweg (SAP, 2008 to 2010).

Limited by time and manageability of this research project, we demarcate our focus to the largest ED, the ED Leyweg, and exclude the group of emergency eye patients (±3,500 patients/year). This group of patients is excluded from our research as the ophthalmology treats them at their own clinic, 24 hours a day and 7 days a week.

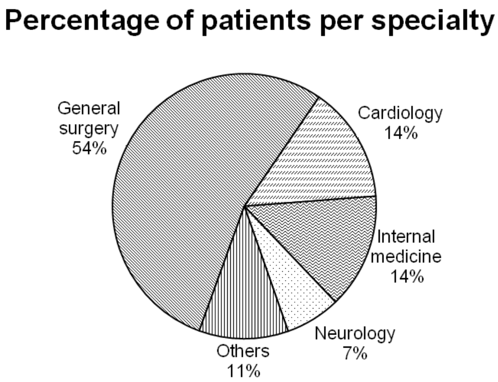

Figure 1.1: Percentage of patients per specialty (SAP, 2010; n=40,541).

1.2 Research objectives

This research is intervention-oriented, because we focus on identifying possibilities to reduce the patient length of stay by reducing waiting times. To achieve this, we divide our research in two parts, each with an own objective. First, we need a clear understanding of the logistical problems at the ED. Qualitative and quantitative insights are needed in the current situation, with the aim to understand how the ED operates and identify the causes of delays. Then, once we identified and quantified the causes of delays, we focus in the second part of this research on identifying possibilities to reduce them. As clearly two steps need to be taken, we define our research objective in twofold:

Objective 1 *Provide insight in the throughput process of the emergency department, by mapping the main patient flows, the activities performed on the patients, the delaying factors in the process, and determine the duration of both activities and waiting times.*

Objective 2 *Recommend interventions to reduce the patient length of stay, by identifying and analyzing possibilities to reduce delays.*

1.3 Research motivation

The ED Leyweg is in need of change. The ED is struggling with high patient length of stays caused by many delays within the patients throughput process. Timeliness of care has a strong correlation with patients satisfaction (Wiler et al., 2010), and staff satisfaction decreases by not being able the help ‘new’ patients quickly and facing the same problems over and over again. Studies have also related waiting time on EDs with unsafe patient situations, and dissatisfied staff with higher chances of resigning and higher levels of absence (Morris et al., 2011). Therefore, quantitative and objective insights are needed into (causes of) waiting times, which can be used to determine interventions.

This research has also a strategic relevance for HagaZiekenhuis. In a more and more competitive health care market, anno 2011, HagaZiekenhuis has identified four profile areas in their strategic plan for 2011-2015. These profile areas represent the areas the hospital desires to accelerate upon regionally, and the acute care is one of them. When waiting times are reduced, patients satisfaction increases, and this benefits the competitive position of the ED in the region.

Finally, this reseach can also be used to create understanding and awareness between staff members of the ED and interacting departments. Patient flows throughout different hospital departments are often segmented, with a lack of a complete overview. Smootening information flows and physical transfers of patients from one department to another enhances departmental performances and reduces staff frustrations on both ends.

1.4 Research questions

To structure our analysis, we use four research questions. By answering these research questions we obtain the information needed to achieve our research objectives. First, we need insight in the current situation, for which we use our first research question.

RQ1 What are the EDs input, throughput and output patient flows, and what are the current activity durations and waiting times on the ED?

In Chapter 2, we answer research question one. We map the different patient flows of the ED, describe activities performed, and quantify activity and waiting times durations. In this way, we obtain insights in the operational performance of the ED, and are able to identify delaying factors.

We also use Section 2.6 to describe the future changes the ED is facing. With the opening of a general practitioner post alongside the ED in May 2012 and possibly the closure of the ED Sportlaan for adult care, the composition of patient flows at the ED likely changes. We forecast the impact of these changes, which we later on take into account when we determine interventions.

After we have completed our contextual analysis and obtained a clear overview of the waiting times and their causes, we need to identify interventions to reduce them.

RQ2 Which literature can we use to determine interventions?

In Chapter 3, we describe useful theories and insights from other studies to identify possibilities to reduce waiting times. We continue by combining the knowledge obtained from literature with common sense to determine customized interventions for the ED Leyweg.

RQ3 Which interventions can we suggest to reduce waiting times and how can we assess them?

We answer this research question in the Chapters 4 and 5. We start in Chapter 4 with identifying promising interventions and divide them in two groups, based on 'whether we need extensive additional research to assess them' or not. The *suggested interventions* *not* *in need of extensive additional research* are investigated and assessed in Chapter 4, while of the *suggested interventions in need of extensive additional research* one highly intervention is selected. We investigate this intervention in detail using a simulation study in Chapter 5. Once we complete our simulation, the last step we take is identifying which of the interventions we are actually going to recommend.

RQ4 Which interventions do we recommend?

In Chapter 6, we draw our conclusions and provide an overview of the interventions we recommend the management of the RVE acute care and ED staff. In addition, we end this research with providing some recommendations for further research.

Chapter 2 Context analysis

The purpose of this chapter is to obtain insight in the throughput process and identify and quantify factors in the process causing waiting times. In literature, multiple factors can be found causing delays in EDs, but the presence or absence of these factors differ between EDs (Hall et al., 2006; Paul et al., 2010). Since we do not know which factors are relevant for the ED Leyweg, we need to conduct a descriptive and quantitative analysis on all system components of the ED to identify delaying factors. The question that naturally arises is: where to look for?

The answer is found in manufacturing theories (Hopp and Spearman, 2000). When considering logistical performance, there are three basic principles leading to improvement: (1) *reduction of waste*, e.g. less rework or down times, (2) *reduction of variability*, e.g. less fluctuations in demand or more constant service times, and (3) *reduction of complexity,* e.g. standard working methods. These principles are derived from theories of lean manufacturing and factory physics and described in more detail in Chapter 3. For now, we use these principles to identify possibilities for improvement in our contextual analysis.

Additionally, to place a value judgment upon *sources of variability* identified, we use the coefficient of variation (CV). The CV is calculated by dividing the sample standard deviation (σ) by the sample mean (µ), and the variety is classified as *low* when CV < 0.75, *moderate* when 0.75 ≤ CV ≤ 1.33, and *high* when CV > 1.33 (Hopp and Spearman, 2000). Hopp and Spearman´s *law of variation* states that the performance of a production system always decreases when variability in the system increases, yielding that sources of high variability provide good opportunities for improvement.

Further, to structure our context analysis, we use the *system approach* and describe the ED using the *input-throughput-output* model (see Section 2.1). We also mention the *factors that cause waiting times* identified during the analysis separately in bold, and refer to them by the abbreviation of the words **Delaying Factors**, i.e. **DF**.

Chapter's structure

We start this chapter with Section 2.1, in which we provide an overview of the methods used to perform our descriptive and quantitative analysis. The analysis itself starts in the second section. In Section 2.2 to 2.4 we analyze the *Input-, Throughput-,* and *Output flows* respectively. Section 2.5 is used to describe the *availability and allocation of resources*, and in Section 2.6 we investigate the changes the ED is facing. The chapter ends with an overview of the identified delaying factors in Section 2.7.

2.1 Methodology

In Subsection 2.1.1, we start with a description of the *system approach*, and apply this method to determine the place of the ED in the broader health system and map the EDs throughput process. In Subsection 2.1.2, we continue with a description of the methods and sources used to gather the data and information required for our context analysis.

"It is essential to understand the basic relationships governing a system before attempting to optimize it" (Hopp and Spearman, 2000, p.190)

2.1.1 System approach

The system approach is a commonly applied method in the field of operations research to analyze organizations for problem solving purposes (Hopp and Spearman, 2000). In this method, organizations are considered as a collection of interacting systems, each with an input, throughput, output and own environment. Each system obtains input from her environment, transforms the input through a collection of interacting activities (called a process), and releases the output back into her environment (Daft, 2004; Hall et al., 2006). Figure 2.1 gives a simplified overview of the system components as defined in the system approach.

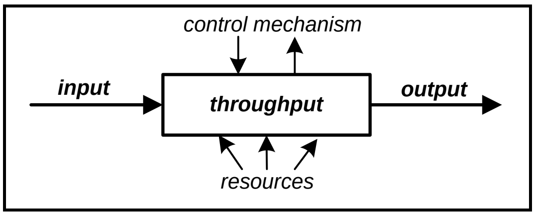

Figure 2.1: Simplified visualization of a (sub)system.

We use the system approach to form the framework of our descriptive analysis by applying the method on two levels of aggregation. We first use the method to describe the position of the ED in the field of acute care delivery and obtain insight in the in- and output flows of the ED. Second, we use the method to describe the ED throughput processes in a structured way, in which we define a throughput process as a sequence of activities performed on a patient.

The ED as subsystem of the acute care system

Tregunno et al. (2004) state that investigations towards improvements of EDs need to be placed within the context of the broader health system to actually understand the way EDs operate. Applying the system approach on the ED, we define the ED as a subsystem of HagaZiekenhuis, and HagaZiekenhuis as a subsystem of the entire acute care delivery system in The Hague region. We provide a systematic overview in Figure 2.2.

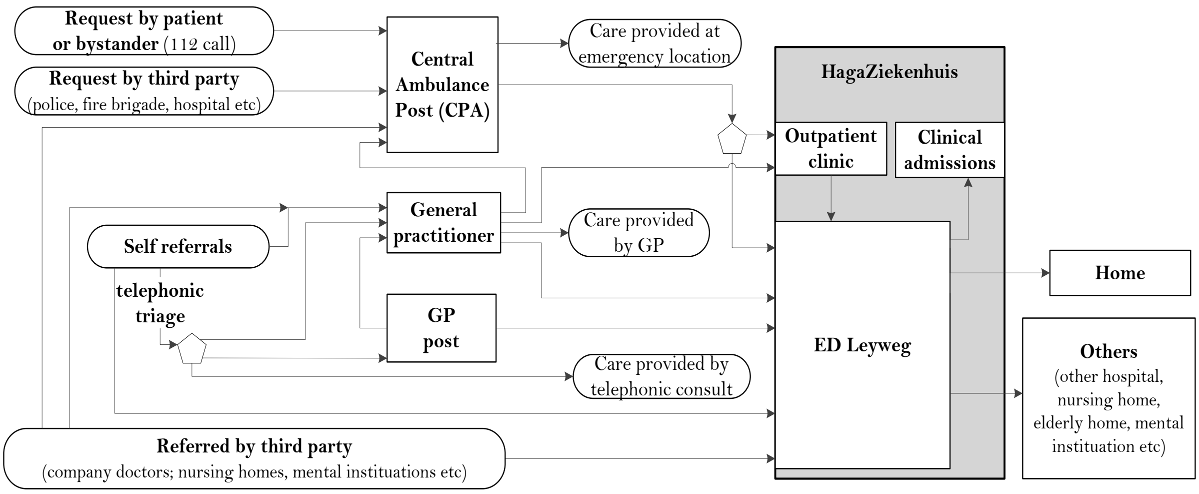

Figure 2.2: Position of the ED within the field of acute care delivery.

Patients attend the ED from other subsystems, both inside (e.g. outpatient clinics) and outside (e.g. general practitioners and ambulances) the hospital, as well as they leave the ED to other subsystems, both inside (e.g. ward, intensive care or operation room) and outside the hospital (e.g. home or other hospital). Therefore, the ED function depends greatly on processes served by external actors (Beach et al., 2003). In Section 2.2 and 2.4, we describe the in- and output flows of the ED in more detail.

The throughput process of the ED

In Figure 2.2, we displayed the ED as 'black box'. In this section, we open the 'black box' and look at the throughput processes. We define a throughput process as a sequence of activities performed on a patient, and are interested in the duration of these activities and waiting times between them.

The ED has many different throughput processes, as different patients require different activities to be performed. However, by systematically analyzing the throughput processes using flow charts and actor activity diagrams, we identified eight main groups of activities, which we refer to as *stages*. The eight stages are: (1) patient registration, (2) triage, (3) nurse anamnesis, (4) first round diagnostics, (5) medical anamnesis, (6) second round diagnostics, (7) diagnosis and treatment, and (8) departure. The diagnostic stages are optionally, but all patients treated on the ED go the other six stages. We provide an overview of the different throughput processes in Figure 2.3, in which we use the eight stages as basis. In Section 2.3, we describe the stages in detail, and quantify the duration of the stages (later on referred to as *service times*) and the waiting times between stages.

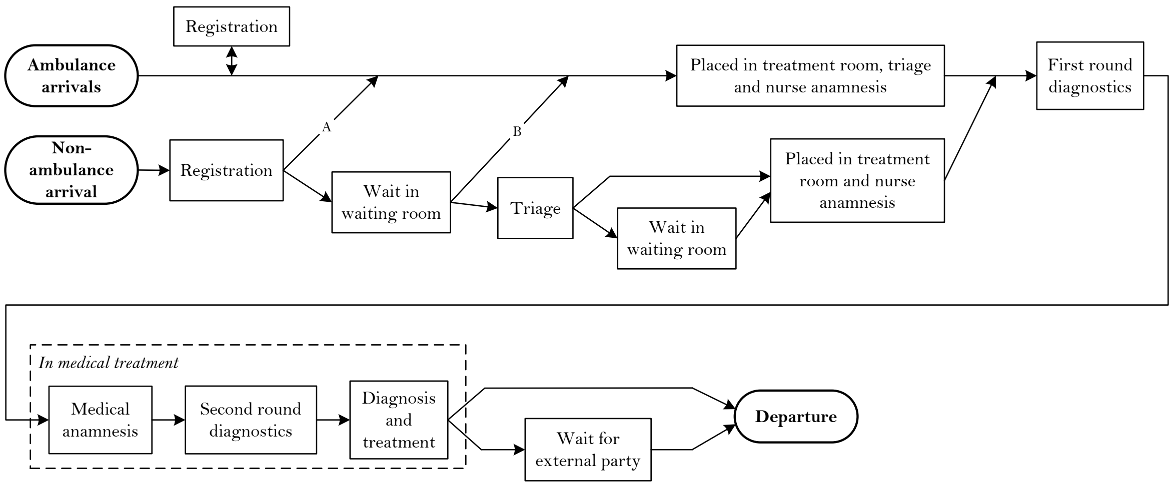

Figure 2.3: Stages throughput process.

The letters A and B in Figure 2.3 are used to designate two specific patient flows, which we describe in more detail in the Subsections 2.3.2 and 2.3.3 respectively.

2.1.2 Data and information gathering methods

A crucial part of research is obtaining reliable data and information. We used four methods to gather our information.

Empirical research (Observations, 2011)

By observations we obtained objective insight in patient flows, staff working processes, and problems faced by staff while working. We joined nurses and ED physicians for six days during their normal working activities, as well as we joined the desk employee for a period of two days, and spent an additional seven days on the ED when we conducted our measurement.

Semi-structured interviews (Interviews, 2011)

In addition to the observations we used semi-structured interviews to gather information. We interviewed nurses and doctors to obtain insight in the problems they are facing concerning the throughput of patients throughout the ED, asked them what they believe to be the main causes, and asked them questions to better understand why processes are the way they are.

Retrospective analysis using electronic patient records (SAP, 2010)

We use a quantitative data analysis for two purposes. The first application is to obtain information on *patient volumes* (Subsection 2.2.1), *waiting time to triage* (Subsection 2.3.3), *time to initial doctor contact* (Subsection 2.5.3) and *moment of patients departure* (Subsection 2.5.3). All patients who attended the ED in 2010 are included (n=40,541) and the program SAP is used to obtain the data from the different individual electronic patient records (EPRs). The second application is to forecast the future changes in patient input flows the ED is facing (see Section 2.6).

Time measurement study (Measurements, 2011)

The times registered in the EPRs are not comprehensive, and we need additional quantitative information on activity service times and waiting times in the processes to understand the time patients spend at the ED and identify bottlenecks. However, as this data is not available, we decide to obtain these times by executing a manual time measurement study.

By using three consultation sessions with five different nurses and four doctors, we have designed time registration forms for which we used the eight stages of a patient stay on the ED (see Subsection 2.1.1) as a basis. We designed two time registration forms, one *patient specific* form and the other a *doctor specific* form. The patient specific form, clearly recognizable by her bright pink color, was kept with the papers of the patient and filled in by the nursing staff. The doctor specific form, printed on bright blue papers, was kept by the doctor, and each doctor had his or her own form on which (s)he registered the initial contact moment with a patient and the moment (s)he ended their last activity for the patient. At the end of the week, we bundled the times reported on the two forms on a patient level, by which we obtain an overview of the service and waiting times of each patient during their stay on the ED.

To increase the chances of the measurement becoming a success, we exploit a foursome preparation activities. First, we conducted a pilot of one day to test working with the forms, and as a 'warm-up' for the actual measurement. Second, we announced both the pilot and the actual measurement in the weekly newsletter of the ED. We shortly explained the purposes, the dates of measurement, and in the second newsletter, we also provided feedback on the success of the pilot. Third, during the week before the pilot, we attended both morning and afternoon nurse meetings (these meetings are attended by the nurses who 'take over the shift') to announce, explain and answer questions about the pilot and measurement. And fourth, we printed bright colored sheets with large texts like *'let op: meetweek'* and '*vergeet de formulieren niet in te vullen*', which we pasted on strategic places inside the ED during the measurement.

The measurement was conducted from 07h30 a.m. on Monday August 1st 2011 to 07h30 a.m. on Monday August 8th 2011, in which all patients on the ED were tracked. During this week 724 patients attended the ED of which we received 665 *patient specific* forms (92%) in return and 436 patients (60%) were registered on the *doctor specific* forms.

In the next five sections (see Section 2.2 to 2.6) we use these four methods to describe and obtain insight in the current processes, with the purpose to identify waiting times and their causes.

2.2 Input flows

In this section, we describe the input flow of patients by analyzing the patient volume (Subsection 2.2.1), the arrival pattern of patients (Subsection 2.2.2), and the patient mix. However, there are several approaches to describe the mix of patients. We use the division of Paul, Reddy and DeFlitch (2010), who state that the three main dimensions commonly used are *case type*, *level of acuity*, and *mode of arrival*. According to the case type, we described in Section 1.1 already the division of patients towards speciality. Therefore, in this section, we describe the remaining two dimensions: acuity of patients (Subsection 2.2.3) and the way patients arrive at the ED (Subsection 2.2.4).

2.2.1 Patient volume

Total number of patients per day

On average 111 patients attend the ED per day (SAP, 2010), with in 80% of the days varying between 96 and 126 patients. Figure 2.4 shows the number of patients per day in 2010.

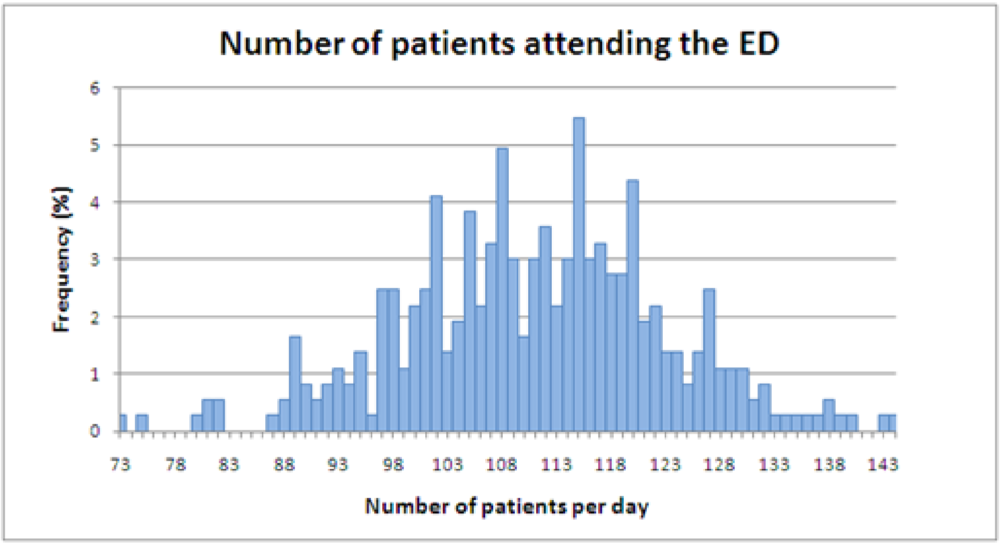

Figure 2.4: Number of patients per day on the ED (SAP, 2010; n=364 days – excl. outlier 165).

Number of patients per day of the week

Considering the days of the week individually, we determine that Mondays and Fridays are the most crowding days of the week, see Figure 2.5. On these days the number of patients attending the ED are significantly higher[1] compared to the other days of the week (two-sided T-test; $H_0{:}\mu_1=\mu_2$; $p<0{,}05$).

The variability of the number of patients attending the ED on a specific day is for all days *low*, with a maximum CV of 0.12 on weekend days. We look at the number of patients attending the ED in more detail in Subsection 2.5.3, when we investigate the fit between demand and staff capacity available.

[1] *Although between Thursday and Friday no significant difference was found (p=0.055)*

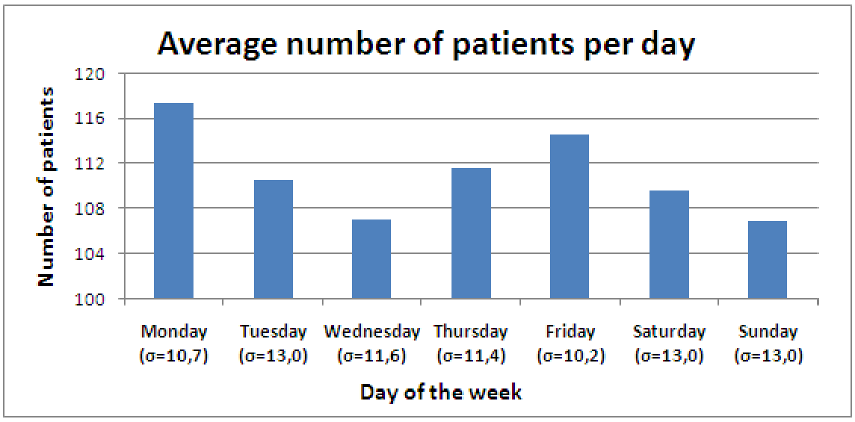

Figure 2.5: Average number of patients per day of the week (SAP, 2010; n=40,541).

2.2.2 Arrival pattern of patients

The number of patients attending the ED during the day is characterized by a clear *S-shaped* pattern (SAP, 2010), a commonly found pattern in EDs (Green, 2007; Rosmulder, 2011; Walley, 2003). Figure 2.6 shows the time varying demand pattern. The line indicates the average number of patients attending the ED per hour of the day. The colored area in the background shows the 95-percentile of incoming patients, e.g. in 95% of the days at most 13 patients have arrived at the ED between 13h00 and 14h00.

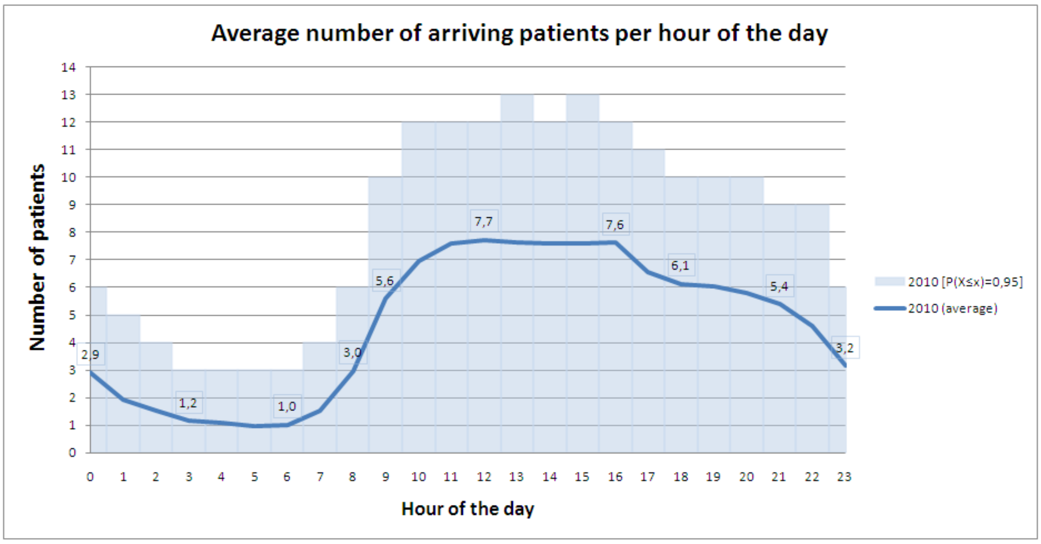

Figure 2.6: Average number of arriving patients per hour of the day (SAP, 2010; n=40,451).

In Figure 2.6, we see that most patients attend the ED between 10h00 and 18h00. During these hours 53.3% of all patients attend the ED, with an average of 7.4 patients per hour. We observe that during this period of eight hours the average inflow of patients is relatively constant. Surprising is that the ED staff indicates that the most crowded moments are between 15h00 and 22h00 (Interviews, 2011). An explanation is that the number of patients in the system follows the S-shaped pattern of arriving patients, but only shifted in time. We analyze the fit between demand and availability of staff capacity in more detail in Subsection 2.5.3.

2.2.3 Urgency of patients

All patients arriving at the ED are triaged in order to prioritize patients according to the urgency of their care need. To perform the triage, the ED uses the Manchester Triage System (MTS). The MTS distinguishes 54 categories of complains and by answering questions like; *airway threatened?* or *vomiting blood?*, the priority of a patient's care need is determined. The MTS works with five categories of priority, all indicated with a specific color. Each color corresponds with a maximum time in which the patient has to be seen by a doctor, measured from the moment of arrival (MTS Group, 2002). Table 2.1 gives an overview of the priorities, the corresponding maximum allowed waiting time to initial doctor contact, and the percentages of patients per urgency category (SAP, 2010).

Urgency category	Maximum waiting time (min)	Percentage of patients (%)
Immediate	0	1.1
Very urgent	10	17.8
Urgent	60	41.1
Standard	120	38.8
Not urgent	240	1.3

Table 2.1: Urgency categories by the Manchester Triage System (SAP, 2010; n=40,541).

Table 2.1 shows that most patients are not in immediate or very urgent care need. 41.1% of all patients can wait for one hour, 38.8% for two hours, and 1.3% even for four hours. An important performance indicator of EDs is the percentage of patients who had their initial doctor contact within the maximum set waiting time by triage, which we further investigate in Subsection 2.5.3.

2.2.4 Ways of arrival

In Figure 2.7, we provide a simplified schematic overview of the main in- and output flows of the ED. In this subsection, we focus on the input flows. The output flows are described in Section 2.4.

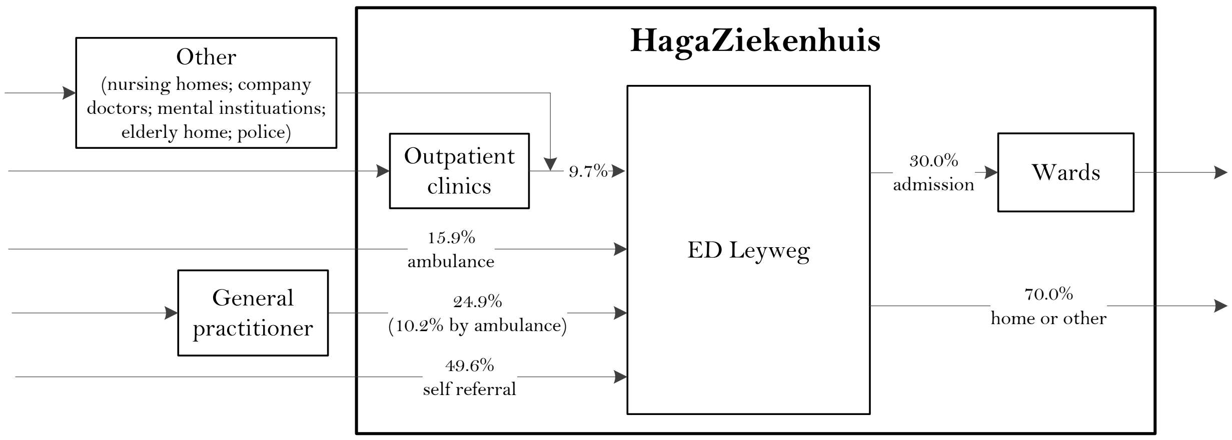

Figure 2.7: Overview of input and output flows of patients at the ED Leyweg (SAP, 2010; CPA, 2010; input, n=40,394; output, n=34,992).

Self referring patients

The group of self referring patients are the patients who walk in by themselves without a referral from a first or second line care provider. Figure 2.7 shows that 49.6% of all patients attending the ED belongs to this group. However, in the near future, this percentage will change. In May 2012, an integrated emergency post (IEP) is planned to open her doors, in which the ED is going to cooperate with a GP post. For now, much is still uncertain about how the ED is going to operate in the IEP. We describe the IEP in more detail in Section 2.6.

Referred by general practitioners

The group of patients registered as *arrival referred by a GP*, can be referred by their own GP, by a GP from a GP post, or they are referred to the ED after telephonic triage of a GP post (see Figure 2.2). This group of patients contains 24.9% of all patients.

Ambulance arrivals

In this report, we refer to the group of patients brought in by ambulance as 'ambulance arrivals'. These patients can either be referred by a care provider (e.g. a GP or doctor from another hospital), or they are non referred and brought in after an 112 call. In total, 26.1% of all patients are brought in by an ambulance, of which 10.2% after being referred by a GP (see Figure 2.7).

In terms of patient logistics, the ambulance arrivals are a specific group. In contrary to 'non-ambulance arrivals', ambulance arrivals are always directly placed inside a treatment bed at arrival and never inside the waiting room (Observations, 2011). Normally they are placed inside a treatment room, however, when all rooms are occupied they can be placed on a bed in one of the hallways. We refer to these beds as *hallway beds,* and provide additional information upon the usage of hallway beds in Subsection 2.5.1.

Remaining group

The remaining 9.7% of patients (see Figure 2.7) contains of a mix of patients. These patients are either send to the ED by a specialist from an outpatient clinic, a first line doctor other than a GP (e.g. a doctor working in a nursing home or industrial company), or brought in by the police.

During conversations with ED physicians and nurses we noticed major frustrations by *illegitimate* users of ED resources. The illegitimate users are specialists who refer patients to the ED, instead of taking care of these patients at their outpatient clinics. Based on the conversations, we distinguish three groups of *illegitimate* patients:

I. The first group consist of patients who are referred to the ED by a general practitioner (GP) due to planning or capacity problems at the outpatient clinics. These patients should be treated at the outpatient clinic, but as the patient cannot be seen within a short time frame the GP decides to refer the patient to the ED. Especially the outpatient clinic of the cardiology causes problems (Interviews, 2011). To clarify, e.g. the first moment a patient can be seen at the outpatient clinic of the cardiology is in three days. Although some patients who are seen by their GP are not in immediate need of care, the GP perceives three days as unsafe, or the patient is anxious, and the GP refers the patient to the ED. One of the ED nurses estimate that 20-30% of all patients attending the ED for the specialty cardiology belongs to this group.

II. The second group consists of patients who are indirectly referred to the ED, after being treated at an outpatient clinic. These patients are told at the clinic that whenever they have problems, they can come to the ED. The ED staff believes these patients should be taken care of at the outpatient clinic if the care need of the patient is not acute or very urgent.

III. The third group consists of patients who are referred to the ED for a checkup. The ED is used as emergency outpatient clinic, caused by planning problems at the outpatient clinics. E.g. a patient is treated at an outpatient clinic and needs to be checked within two days. However, due to planning problems the patient does not fit within the schedule and is told to come back at the ED in two days.

Literature shows that frustration among staff is positively related with increased chances of medical risks and a decrease in productivity (Wiler, 2010). But besides staff working 'slower' when they are frustrated, we also observed that time is lost by nurses discussing the situation once again when an *illegitimate* patient attends the ED. Unfortunately, no data is available to determine the percentage of *illegitimate* patients in the total subgroup of 9.7% of all patients.

DF_1 Productivity of staff decreases by increasing levels of frustration and discussing these frustrations, caused by patients *illegitimate* attending the ED.

2.2.5 Conclusions 'input'

- The number of patients attending the ED is significantly higher on Mondays and Fridays.
- The variability in the number of patients per day of the week is *low* for all days.
- Most patients arrive between 10h00 and 18h00, with an average of 7.4 patients per hour.
- 49.6% of all patients are *self referring* patients and 26.1% arrives by ambulance.
- [DF_1] The productivity of staff decreases by increasing levels of frustration and discussing these frustrations, caused by *illegitimate* patients attending the ED.

2.3 The throughput process

In this section, we analyze the aspects of the throughput process in detail. In the Subsections 2.3.2 to 2.3.7, we describe the different stages of a patients stay, provide insight in the activities performed on the ED, and search for delaying factors by quantifying service and waiting times. But we start, in Subsection 2.3.1, with determining the current patient length of stay to get an understanding of the size of the problem.

2.3.1 Patient length of stay

The patient length of stay ('patient LOS') is the time in between the moment a patient arrives at the ED and leaves the ED. In the Netherlands, the Dutch National Institute for Public Health and Environment uses the patient LOS to judges ED performances. Patients should leave the ED within maximum 4 hours after arrival and the higher the percentage of patients meeting this target, the better the EDs performance (RIVM, 2009). However, the management of the RVE acute care of HagaZiekenhuis has set a stricter target, stating that patients should leave within maximum 3 hours after arrival (Jaarplan RVE Acute Zorg, 2011, p8).

To determine how the ED is performing in terms of patient LOS, we provide an indication of the patient LOS of the four specialties who together treat 89.2% of all patients (see Section 1.1). Due to inaccurate registration of patient departure times, we are unable to provide the exact patient LOS. Therefore, we subtract the average inaccuracy found during our measurement from the patient LOS obtained of all patients in 2010 (SAP, 2010). From our measurement we know that the inaccuracy is not correlated with the total length of patients staying, and therefore we assume this method provides a reliable indication. In Figure 2.8, we provide the patient LOS of the largest four specialties divided towards urgency, while an overview of the average inaccuracy in departure time registration can be found in Appendix A.

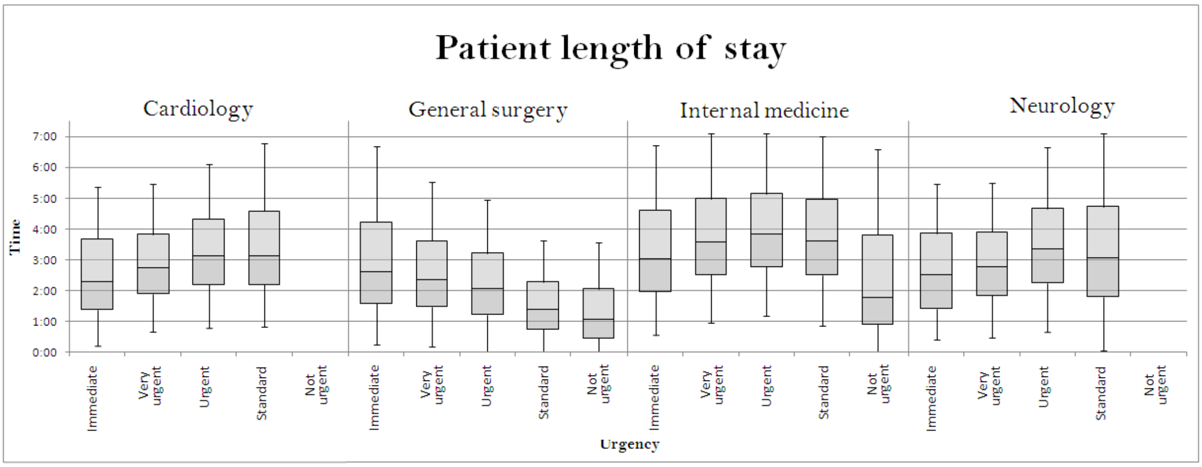

Figure 2.8: Patient length of stay (SAP, 2010; n=35,563).

Based on Figure 2.8, we conclude that both the 3 hour and 4 hour targets are often not met. The internal medicine scores worst, followed by neurology, cardiology and general surgery. In Table 2.2, we provide a structured overview of the average patient LOS per specialty, and the percentages of patients having a patient LOS within the norm of 3 and 4 hour respectively.

Specialty	Average patient LOS	Number of patients within norm	
		3 hour	4 hour
Cardiology	3:11:33	54%	75%
General surgery	2:04:46	79%	90%
Internal medicine	4:04:53	33%	56%
Neurology	3:30:28	47%	67%

Table 2.2: Percentage of patients with a LOS within the norm (SAP, 2010; n=35,563).

Note that the 3 hour norm is set by the HagaZiekenhuis, while the national used norm to judge EDs upon their performance is 4 hours (RIVM, 2009). According to the manager of the RVE acute care the 3 hour norm is chosen as it was believed to be achievable.

Stages of the throughput process

2.3.2 Registration

Patients are registered by the desk employee at the front desk when they arrive. Ambulance arrivals are immediately placed in a room or hallway bed, while the patients´ attendance is reported at the front desk by one of the ambulance nurses, the STIP nurse or the treating ED nurse. Non-ambulance arrivals announce their presence themselves at the front desk. The desk employee registers the patient, and meanwhile estimates the urgency of the patients care need. If she estimates that immediate care is needed, she calls a nurse and/or resident and the patient is immediately taken to a treatment room. This group is displayed by *path A* in Figure 2.3 and is quantified in Subsection 2.3.3. If the patient is not perceived being in an immediate care need, the patient is asked to take a seat in the waiting room. The desk employee prints a sheet of stickers with patients information (like name and birth date) and places these on the bottom of the 'triage box' for the triage nurse. However, if the desk employee *feels* that the person should be triaged faster than other patients, she might place the sheet of that person somewhere earlier in the stack of sheets.

The mean service time of registration, which we define as the time between the moment a patient start his/her conversation with the desk employee to the moment the registration is finished and the patient is asked to take a seat in the waiting room, is 2 minutes and 25 seconds (Measurements, 2011; n=35; σ = 0m59s). The waiting time in front of the reception desk differs. Depending on the number of patients arriving within minutes after each other, patients might have to wait on each other. However, we do not believe that the waiting time in front of the reception is a delaying factor of importance on the ED, and neither do we believe that it is of interest to search for opportunities to speed up the time it takes to perform the registration.

2.3.3 Triage

Triage is a management tool to control the queue of patients waiting to be seen by a doctor by prioritizing patients on the urgency of their care need at arrival (NVSHV, 2008). Waiting is a non value adding activity and disliked by patients (Boudreaux, 2004). Besides, triage in itself is neither a value adding activity for the patients, so both the *waiting time to triage* and the *service time of the triage* activity in itself should be as short as possible (NVSHV, 2008; Wiler et al., 2010). The norm of HagaZiekenhuis (Prins, 2011) equals the norm set by the NVSHV (2008), which states that triage should start maximally 10 minutes after the arrival of a patient. The triage activity itself should be performed within 5 minutes (NVSHV, 2005).

In the remaining part of this subsection, we first describe the triage processes for patients triaged in the triage room and patients triaged in a treatment room, followed by an analysis to determine whether the norms are achieved.

Patients triaged in the triage room

The triage room is situated alongside the waiting room, and during each day of the week one nurse is assigned as triage nurse between 07h30 and 23h15. The triage nurse takes the sheet on top of the 'triage box', calls the patient from the waiting room, and performs the triage. During our measurement, patients waited on average 7 minutes and 17 seconds in the waiting room before taking in for triage, measured from the moment their registration was finished (Measurements, 2011; n=324; σ=8m05s; CV=0.90). The average service time of triage, defined as the time a patient spends inside the triage room, was 5 minutes and 39 seconds (Measurements, 2011; n=302; σ=2m54s; CV=0.51), or, when blood was already taken inside the triage room to start diagnostic blood tests, 8 minutes and 4 seconds (Measurements, 2011; n=14; σ=4m49s; CV=0.60). Although taking blood is not 'meant to be done' inside the triage room, occasionally nurses execute these activities on their own initiative to speed up the process. When the triage is completed, the patient is either placed back in the waiting room or directly taken to a treatment room. Note that independent of whether blood is started by the nurse, the variability in service time to triage can be classified as *low*, but the variation in waiting time to triage is *moderate*.

Patients triaged in the treatment room

The patients who are triaged in a treatment room are the ambulance arrivals and patients who are taken from the triage room before being triaged. Let us first consider the patients brought in by ambulance.

Ambulance arrivals are triaged inside the treatment room, commonly in combination with the nurse anamnesis (see next paragraph). Although we did not observe this, conversations reveal that nurses sometimes perform the triage as an individual activity and perform the anamnesis later on. The time ambulance arrivals have to wait to be placed in a treatment room is negligible, and the average service time of the triage and nurse anamnesis together is 6 minutes and 2 seconds (Measurements, 2011; n=92; σ=4m12s; CV=0.70).

The second group triaged in a treatment room are the non-ambulance arrivals who are taken to a room before being triaged. During our measurement this group contained 23.6% of all non-ambulance arrivals, of whom 5.7% was directly taken to a treatment room after registration (see *path A* in Figure 2.3) and 17.9% was first placed in the waiting room, but taken to a treatment room before triage (see *path B* in Figure 2.3). From now on, we refer to these groups as *direct patients* and *indirect patients* respectively. The waiting time before triage of the *indirect patients*, measured from the moment their registration is finished, is on average 11 minutes and 54 seconds (Measurements, 2011; n=80; σ=10m43s), and the variation in this waiting can be classified as moderate (CV=0.90).

Placing a value judgement: are the norms met?

The norm concerning the triage duration states that the triage should be performed within 5 minutes (NVSHV, 2005). When no blood is taken by the triage nurse, we determined that the average service time is 5 minutes and 39 seconds, and 42% of the service times exceeding the 5 minute norm. But when blood tests are started by the triage nurse, the average service time increases to 8 minutes and 4 seconds and this results in even more patients not triaged within the 5 minute norm. We can not place conclusions upon the triage duration for ambulance arrivals, as the triage and nurse anamnesis are performed at once within this group.

DF_2 The service time of triage is with an average of 5 minutes and 39 seconds too long, resulting in 42% of the non-ambulance arrivals not triaged within the norm of 5 minutes. When blood tests are started during triage the service time is, with an average of 8 minutes and 4 seconds, even longer.

But is the 10 minute norm (NVSHV, 2008; Prins, 2011) of *waiting time to triage* met? The two groups of patients affected by a waiting time to triage are the patients who are actually triaged in the waiting room, and the *indirect* patients who were taken out of the waiting room before triage. We provide an overview of the average waiting times to triage and the percentage of patients who waited longer than the 10 minute norm in Table 2.3 (Measurements, 2011).

Specification patients	n	Average waiting time to triage	Percentage > 10 min
Triaged in triage room	324	7m17s	28%
Indirectly taken	80	11m54s	37%

Table 2.3: Percentage of patients within norm of waiting time to triage (Measurements, 2011).

DF_3 The triage of 28% of the patients triaged in the triage room and 37% of the patients taken indirectly is not started within the 10 minute norm.

2.3.4 Nurse anamnesis

The nurse anamnesis consists of a collection of small activities, performed by a nurse to prepare the patient for the doctor. If the patient is a non-ambulance arrival, the nurse first calls the patient from the waiting room, escorts the patient to their treatment room, places the patient on a bed, asks the patient questions to find out what happened, briefly assesses the patient on their vital functions and reports his/her findings in the electronic patient record of the patient. If the patient arrives by ambulance, the same activities are performed, except that the patient does not have to be taken from the waiting room.

Non-ambulance arrivals often have to wait between triage and the moment they are taken to a treatment room and the nurse anamnesis starts. During the measurement, patients waited on average 24 minutes and 44 seconds (Measurements, 2011; n=171; σ=31m02s; CV=1.27) before taken to a treatment room on the low care area, while the average waiting time for patients on the medium or high care area is 13 minutes and 32 seconds (Measurements, 2011; n=141; σ=24m02s; CV=1.78). Based on these average waiting times and the high coefficients of variation, we conclude that the throughput of patients from triage room to treatment room does not flow smoothly.

DF_4 Non-ambulance arrivals wait on average 13 minutes and 32 seconds after being triaged in the triage room when they need to be placed inside a treatment room on the medium or high care area, and 24 minutes and 44 seconds when placed inside a room on the low care area.

From Figure 2.3 we know that the nurse anamnesis, as separate activity, is only performed on patients who are already triaged in the triage room. In these cases, the average service time of the nurse anamnesis, measured from the moment the patient is inside a treatment room, is 3 minutes and 50 seconds (Measurements, 2011; n=41; σ=4m50s; CV=1.26). When the patient also needs to be triaged, the average duration of the triage and nurse anamnesis together is 6 minutes and 2 seconds (Measurements, 2011; n=92; σ=4m12s; CV=0.70). This duration is noticing, as in Subsection 2.3.3 we determined that the triage as separate activity already takes on average 5 minutes and 39 seconds. A possible explanation is that the same activities are conducted during the triage and nurse anamnesis, yielding that when the triage and anamnesis are performed at once, time is saved by preventing 'rework'. E.g. both the triage nurse and ED nurse ask questions to find out what happened.

2.3.5 First round diagnostics

The most commonly performed diagnostic procedures on ED patients are lab tests, X-ray tests, CT-scans, ultra sonograms, and electrocardiograms. We define the first round diagnostics as the diagnostics requested or performed by nurses <u>without</u> consulting a doctor. The nurse can request/ start two types of diagnostic tests: (1) lab tests in the form of *blood tests* or *urine tests* and (2) making an *electrocardiogram* (ECG).

During the measurement, 75.9% of the blood tests (Measurements, 2011; n=328), 43.1% of the urine tests (Measurements, 2011; n=65), and 81.7% of the ECGs (Measurements, 2011; n=218) were made on the initiative of the treating nurse without interference of a doctor.

Considering the service times of requesting the tests, we know from Subsection 2.3.4 that a nurse anamnesis normally takes 3 minutes and 50 seconds when no diagnostic tests are started. However, when blood samples are taken and a blood test is requested, the average duration of the nurse anamnesis is 10 minutes and 12 seconds (Measurements, 2011; n=55; σ=5m11s; CV=0.51) and, when blood samples are taken and an ECG is made, the average duration is 13 minutes and 24 seconds (Measurements, 2011; n=122; σ=6m02s; CV=0.45). In Subsection 2.5.2, we describe the tests and their durations in more detail.

2.3.6 In medical treatment

We define the period of a patient being in medical treatment, as the start of stage 5 *medical anamnesis* to the end of stage 7 *diagnosis and treatment* (see Figure 2.3). During these stages, the patient is in treatment of a doctor.

The medical treatment starts with a medical anamnesis in which the doctor takes notice of the patients situation, performs physical examinations, forms a diagnosis, decides whether additional diagnostic tests are necessary to set or verify a diagnosis, and finishes with administration of the first findings and actions taken in the EPR (Observations, 2011). When diagnostic tests are requested, the doctors have to wait for the results and start working on other patients in parallel. Once the test results are available, they are interpreted and conclusions are drawn. If the results are conclusive, the doctor determines which treatment is needed, often consults the diagnosis and treatment plan with his/her supervisor, and determines the next activity or location of the patient. This can be a treatment (e.g. receiving plaster), discharge or admission. On the other hand, when the test results are not conclusive, additional tests can be requested, specialists consulted, or a residence of another specialty asked for an intercollegiate consult.

The time that patients are in medical treatment varies, especially due to the diagnostic tests that need to be performed. In Table 2.4, we provide an overview of the average duration of patients *in medical treatment* for the four largest specialties (Measurements, 2011).

Specialty	**n**	**Mean** (min)	**StDev** (min)	**CV**
General surgery (low care)	167	33	30	0.91
General surgery (medium/ high care)	74	86	55	0.65
Internal medicine	45	92	44	0.48
Cardiology	42	84	41	0.49
Neurology	19	105	70	0.67

Table 2.4: Duration patients in medical treatment divided per specialty (Measurements, 2011).

Table 2.4 provides an indication of the time doctors spend on their patients. From this table, we conclude that doctors need far less time to treat patients at the low care area, compared to the medium and high care area, but the time needed fluctuates the most. We cannot place any conclusion on the productivity of the doctors per specialty, as a large part of the service time is caused by the number and types of diagnostic tests executed. Table 2.5 shows the average duration of medical treatment of all patients together, divided towards the diagnostic tests they received.

Groups of diagnostic tests		Med./ High care n	Mean (min)	StDev (min)	Low care n	Mean (min)	StDev (min)
I	No test	15	46	52	110	23	24
II	X-ray	4	71	50	68	37	22
III	Lab	95	77	41	9	58	35
IV	Lab & X-ray	43	83	40	7	108	49
V	CT-scan or ultra sonogram (USG)	4	100	49	-	-	-
VI	X-ray & CT-scan or USG	-	-	-	4	96	11
VII	Lab & CT-scan or USG	36	126	55	3	112	40
VIII	Lab & X-ray & CT-scan or USG	12	131	61	-	-	-

Table 2.5: Duration of patient being in medical treatment divided toward the composition of diagnostic tests obtained (Measurements, 2011; n=410).

From Table 2.5, we conclude that the patients duration of medical treatment is strongly correlated with the kind and number of diagnostic tests received. The average duration of medical treatment is lowest for patients who do not need any diagnostic tests and highest when lab tests, an X-ray and a CT-scan or ultra sonogram is needed. In Subsection 2.5.2, we investigate the diagnostic tests in more detail.

Considering the time patients are in medical treatment, we identified that the patient throughput process is delayed by doctors asking supervisors or colleagues of other specialties ('intercollegiate consult') for a consult. Doctors often have to wait before they can consult with their supervisor by phone, or have to wait for their supervisor to arrive at the ED, as well as that colleagues asked in consult commonly first finish their own patients before going in consult (Observations, 2011). We have no data to support the delay caused by the supervisors, but the delay caused by the intercollegiate consults is on average 23 minutes and 51 seconds (Measurements, 2011; n=13; σ=22m23s; CV=0.94). This is the time it takes between the moment a colleague is asked in consult and that the doctor has his/her initial contact with the patient.

DF_5 The patients throughput process is delayed when doctors must wait for their consult with a supervisor or wait for the supervisor to arrive at the ED.

DF_6 The waiting time between the moment a doctor is asked in consult by a colleague and the actual initial patient contact of the requested doctor is 23 minutes and 51 seconds (CV=0.94).

We also encountered that patients face delays caused by doctors who do not start with a new patient at the end of their working shift. Doctors do often not start with the treatment of new patients approximately a half an hour before the end of their shift (Observations, 2011).

DF_7 Doctors do not start with a *new* patient at the end of their working shift.

2.3.7 Departure

The final stage is the patients departure. In Section 2.4, we describe the different ways of departure in detail.

2.3.8 Conclusions 'throughput'

- A significant part of patients does not leave the ED within the 3 hour norm set by HagaZiekenhuis (Jaarplan RVE Acute Zorg, 2011) or national norm of 4 hours (RIVM, 2009), see Table 2.2.
- 56.4% of all patients is triaged in the triage room, 13.2% is taken indirectly, and 4.2% directly. In Figure 2.9 we provide an overview of the percentage of patients per flow.

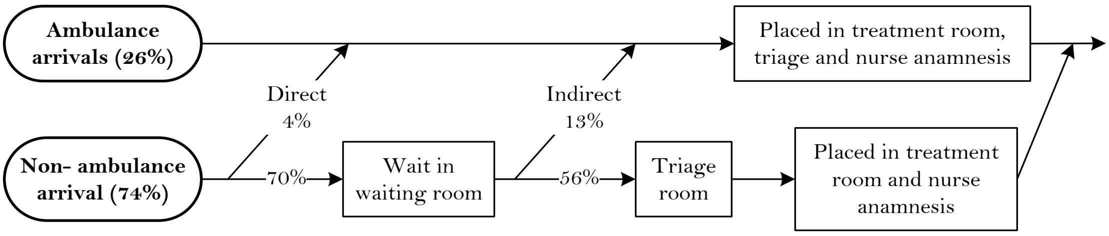

Figure 2.9: Percentage of patients per patient flow up to placement in a room (Measurements, 2011; n=724).

- [DF_2] The service time of triage is in 42% of the patients longer than the maximum 5 minute norm (NVSHV, 2005). The average service time of triage, defined as the time a patient is in the triage room, is 5m39s (CV=0.51) when the triage nurse starts no blood tests, and 8m04s when (s)he does (CV=0.60). The variation in these service times are both *low*.
- [DF_3] 28% of the patients triaged in the triage room have to wait longer than the maximum 10 minute norm to start the triage (NVSHV, 2008; Prins, 2011), while of the patients who are eventually taken indirect 37% have to wait longer than the maximum 10 minutes. The average waiting time before triage is 7m17s (CV=0.90), and the group of patients taken *indirectly* wait on average 11m54s (CV=0.90). Both variations in this waiting time are classified as *moderate*. These variations are caused by the variation in triage service time and variation in the arrival process of patients.
- [DF_4] Patients wait on average 13m32s (CV=1.27) after triage in the triage room for placement in a treatment room on the medium or high care area, and 24m44s (CV=1.78) for placement in a room on the low care area. The variations in these waiting times are *moderate* and *high* respectively, and these waiting times are caused by a combination of *room availability*, *nurse availability* and *urgency of the patients care need*.
- Once patients are placed inside a room, a nurse performs his/her anamnesis, the patients needs to wait for a doctor (see Figure 2.14), and when the doctor arrives the medical treatment is started. The average service time of the nurse anamnesis is 3m50s (CV=1.26) when the patient is already triaged, while 6m02s (CV=0.70) when the triage and nurse anamnesis are combined. Then, from the moment the doctor starts his/her treatment, the average service time of patients being in medical treatment is 33 minutes (CV=0.91) when the patient is treated on the low care, while 89 minutes (CV=0.57) when treated on the medium/high care.
- Within the period a patient is in medical treatment, we identified three causes of delays:
  - [DF_5] The patient throughput process is delayed when doctors must wait for their consult with a supervisor, or wait for the supervisor to arrive at the ED.
  - [DF_6] The waiting time between the moment a doctor is asked in consult by a colleague and the actual initial patient contact of the requested doctor is 23m51s (CV=0.94).
  - [DF_7] The treatment of a patient is not always started when doctors are at the end of their working shift.

2.4 Output flows

In literature a recognized delaying factor at EDs are so called *boarders.* Boarders are patients who need to be admitted to the hospital, but are waiting in the ED until an inpatient bed is available (Asplin et al. 2003; Cowan and Trzeciak, 2005). From Figure 2.7 we know that 70% of the patients leaving the ED are discharged and 30% are admitted (SAP, 2010; n=34,992). However, as *boarders* are not the only patients waiting at the ED before they can depart, we define two new groups of patients departure: group 1*, patients who leave immediately*, and group 2, *patients who have to wait for an external party before they can leave*. These groups represent 66.7% and 33.3% respectively of all patients departing the ED (Measurements, 2011).

2.4.1 Patients who leave immediately

We define the group of *patient who leave immediately* as all patients who leave the ED by themselves directly after their medical treatment is finished. Although a nurse might need to conduct a small activity before the patient is actually discharged, e.g. taking out a blood needle or providing a sling, we have not identified delaying factors of importance in this discharging process.

2.4.2 Patients who have to wait for an external party before they can leave

We define the group of *patients who have to wait for an external party before they can leave* as all patients who need to wait for an external actor of a sequentially linked system with the ED, e.g. a nurse from a ward. These actors form a bottleneck when not directly available, as the patient must wait for the external actor to leave the ED. Waiting is a non value adding activity for the patient and the patient possibly impairs the access to care of other patients by occupying a treatment room while waiting. In here, we distinguish three patient flows of relevance: patients who need to be admitted (30.1%), patients who need to be transported to e.g. another hospital, elderly home, nursing home etc. by ambulance or lay-cab (2.4%), and patients who need to be seen by the *crisis service* (0.8%) (Measurements, 2011; n=724).

Admissions

Patients can be admitted directly from the ED on one of the wards or via the acute admission and diagnostic unit (AADU). In this paragraph, we start with a description of the admission process in general, followed by a description of the AADU.

The admission process differs between hours of the day. The process starts with a resident informing the nurse that a patient must be admitted on a ward or on the AADU. During in-office hours of the admission office, 07h30 to 17h00, the nurse calls the admission office, the admission office checks where a suitable inpatient bed is available, and assigns the patient to a bed directly or calls the nurse back later on when first an available bed has to be sought. The nurse informs the resident, and calls the ward to inform them that there is a patient on the ED that needs to be admitted on their ward. The ward sends one or two nurses to the ED, the patient is transferred to the ward nurses by an ED nurse or the resident, and the patient is transported to the ward. In Figure 2.10, we provide a schematic overview of this admission process between 07h30 and 17h00.

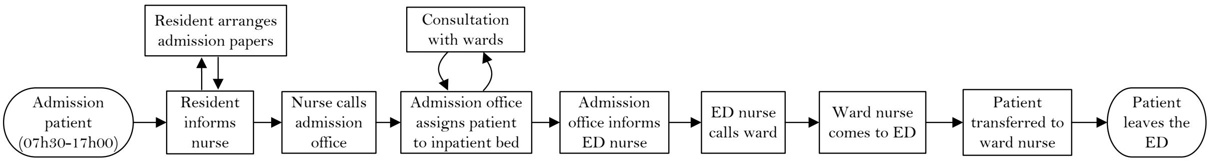

Figure 2.10: Schematic overview admission process between 07h30 and 17h00.

During out of office hours, the admission office is closed. From 17h00 to 23h15 the ED desk employee arranges the patient admissions using a digital overview of available inpatient beds and calling the wards. Once an inpatient bed is found, the desk employee registers the patients admission in the system and calls the ED nurse. The ED nurse fills in an *admission form* for the administration of to the admission office (to inform them about the admission) and informs the resident on which ward the patient will be admitted. During the night hours, from 23h15 to 07h30, no ED desk employee is available either. During these hours the ED nurse calls the *night coordinator*, who assigns patients to beds on wards. The *night coordinator* arranges the admission and also takes care of the *admission form* for the administration of the admission office.

From Figure 2.10, we conclude that the procedure to admit a patient is complex. Many actors are involved and many phone calls have to be made. But how efficient is this process, i.e., how long does it take to find an inpatient bed?

We conclude that an inpatient bed is found faster in the evening between 17h00 and 23h15 than during the daily hours between 07h30 and 17h00. Measured from the moment a doctor decides to admit a patient, it takes on average 16 minutes and 39 seconds (Measurements, 2011; n=79; σ=22m15s; CV=1.34) to find an inpatient bed between 07h30 and 17h00, compared to 11 minutes and 25 seconds (Measurements, 2011; n=55; σ=14m05s; CV=1.23) between 17h00 and 23h15. A problem only arises when we want to answer the question whether these times are waiting times for the patient, because it depends. We observed that most often the process of allocating an inpatient bed is started parallel with ending the treatment of a patient. However, sometimes it does not, and in these cases the time it takes to find a bed can be classified as non value adding waiting time for the patient. We have no data to support this.

We define the actual waiting time to admission, as the time between the moment the nurse calls the ward that the patient can be taken (see Figure 2.10) and the moment the patient actually leaves the ED. We measured these times and found an average of 23 minutes and 31 seconds between 07h30 and 17h00 (Measurements, 2011; n=25; σ=29m20s; CV=1.25) and an average of 16 minutes and 19 seconds between 17h00 and 23h15 (Measurements, 2011; n=35; σ=19m37s; CV=1.20). In terms of performance, HagaZiekenhuis has set a norm of 30 minutes in which a patient must leave the ED towards a ward, measured from the moment the ward is called (Jaarplan RVE Acute Zorg, 2011). The percentage of patients not being admitted within this norm is 28% between 07h30 and 17h00 and 14% between 17h00 and 23h15.

DF_8 Patients who are admitted (30.1% of all patients) wait on average 23 minutes and 31 seconds between 7h30 and 17h00 (CV=1.25), or 16 minutes and 19 seconds between 17h00 and 23h15 (CV=1.20), to be taken in by ward nurses measured from the moment the ward was called.

We also noticed that often during an early stage of the patient stay, the resident already decides to admit a patient, but many activities (e.g. blood tests or X-ray pictures) are performed before the patient leaves the ED. We believe in here lies a good opportunity for using the AADU. The AADU was recently opened in May 2011, has 16 beds, and is used by the specialities *internal medicine* and *general surgery* to admit patients. Although the AADU is meant as an admission and diagnostic centre to ease the ED, in practice, patients are not send to the AADU before all tests are done and a complete diagnosis and treatment is set.

Finally, patients of the specialty *cardiology* and patients who need to be admitted at the intensive care are not admitted via the admission office or desk employee. The residents arrange these admissions themselves with the departments, as well as they arrange transferrals to other hospitals when no beds are available in HagaZiekenhuis. Compared to the other residents, arranging the admissions is an additional task for the resident of the cardiology, who already perceive high levels of workload (see Subsection 2.5.3).

Transport to external facility

Alongside the patients who are admitted, the second group of patients who depend on an external actor to leave are the patients who need to be transported to e.g. another hospital, elderly home, nursing home etc. These patients are transported by an ambulance or lay-cab, and wait on average 1 hour and 3 minutes (Measurements, 2011; n=18; σ=42m01s; CV=0.67) before they leave the ED after their medical treatment was finished. The patients wait for their transport inside a treatment room or in a hallway (Observations, 2011), which is both undesirable.

DF_9 Patients who need to be transported by an ambulance or lay-cab (2.4% of all patients) wait on average 63 minutes to depart (CV=0.67).

Crisis service

The crisis service is a regional service that provides help to people who are mentally confused and are asked in consult by the treating doctor. The mean waiting time before the *crisis service* arrived during the measurement was 1 hour and 38 minutes (Measurements, 2011; n=6; σ=46m38s; CV=0.48) and the duration of the consult was on average 57 minutes and 30 seconds (Measurements, 2011; n=6; σ=20m12s; CV=0.35). The patients waited for the *crisis service* in their treatment room or on a chair in a hallway, but all consults were performed inside a treatment room.

DF_{10} Patients who receive a consult of the *crisis service* (0.8% of all patients) wait on average 1 hour and 38 minutes before the service to arrive (CV=0.48).

2.4.3 Conclusions 'output'

- 66.7% of all patients leaves the ED immediately after their treatment is completed, while the moment of departure of the remaining 33.3% depends on external actors:
  - [DF_8] 30.1% is admitted. From the moment the ward is called, they wait on average 23m31s between 07h30 and 17h30 (CV=1.25) and 16m19s between 17h30 and 23h15 (CV=1.20) to depart.
  - [DF_9] 2.4% need to be transported by an ambulance or lay-cab. They wait on average 63 minutes for their transport (CV=0.67).

- [DF_{10}] 0.8% of the patients receives a consult of the crisis service before they depart. They wait on average 98 minutes before the crisis services arrives (CV=0.48), after which the consult takes an additional 57m30s (CV=0.35).

- The admission process is complex. Many actors are involved and many telephone calls have to be made to find an inpatient bed for a patient to be admitted, see Figure 2.11. The numbers correspond with the steps that need to be taken, and path 4b is followed when the admission office cannot reach the nurse directly. The average time it takes to find a bed is 16m39s between 07h30 and 17h00 (CV=1.34), and 11m25s between 17h00 and 23h15 (CV=1.23).

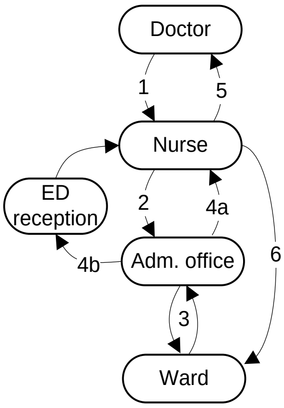

Figure 2.11: Simplified overview of actors involved in finding an inpatient bed.

2.5 Availability and allocation of resources

The ED throughput is limited by the availability of physical capacity and staffing capacity. Releasing work into the system above the capacity causes the system to become unstable, with increasing waiting times as a result. To describe the physical capacity of ED resources, we distinguish between *treatment rooms* (see Subsection 2.5.1) and *diagnostic tests* (see Subsection 2.5.2). We continue with the *availability of staffing capacity* (see Subsection 2.5.3) and end this section with a *conclusion* (see Subsection 2.5.4).

2.5.1 Treatment rooms

Lay out

The ED is divided in three zones. The high care zone (“red zone”) consists of two trauma rooms, and ten treatment rooms of the emergency cardiac care center. The medium care zone (“yellow zone”) consists of three rooms and the low care zone (“green zone”) has ten beds available, located in four different rooms. The largest low care room contains five beds (referred to as the *portacabines*), which are separated by curtains. The other three low care rooms consist of a special ‘attach room’/ room for ‘throat-nose-ear’-patients, a plaster room and a *small injury room* with three small treatment areas. Beside these treatment rooms, there is also an X-ray room, a triage room, a waiting room, and each zone has its own ‘working area’ with computers for the doctors and nurses. In Figure 2.12 we provide a schematic overview of the ED and her different zones.

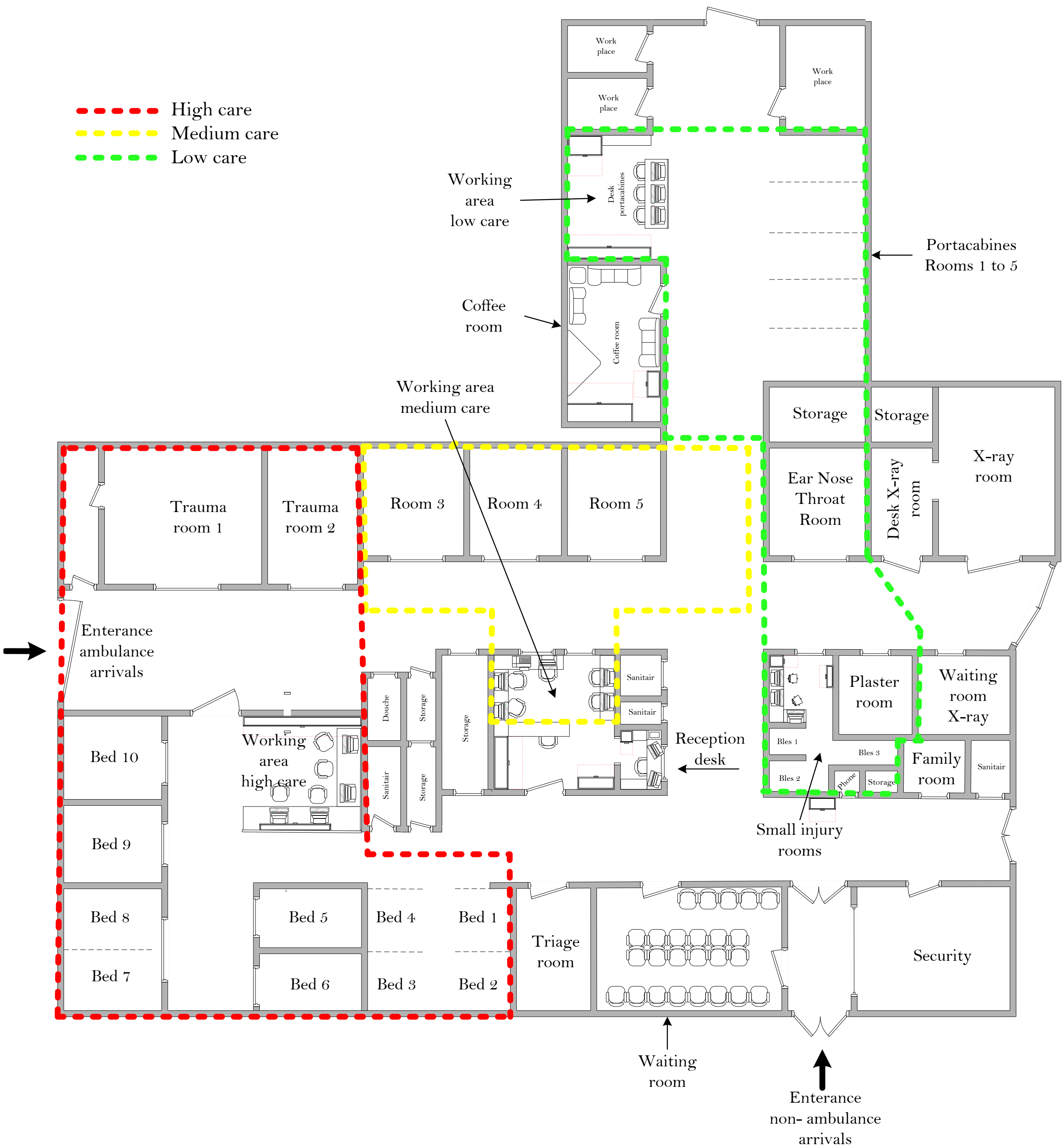

Figure 2.12: Lay-out emergency department.

Although 25 beds are available, only 22 are used during the daily hours and 20 during the evenings and nights. Between 07h30 and 23h15 the small injury rooms are only used occasionally (Observations, 2011), while during the night hours the portacabines are closed. These rooms are not used during these hours as the nurse assigned to the low care area indicate that they cannot keep the overview of both patients in the small injury rooms and the portacabines. Therefore, either one of the areas is used.

Usage of treatment rooms

Most patients are treated in the ten beds of emergency cardiac center, followed by the five portacabine beds. Figure 2.13 shows the number of patients seen in the different areas of the ED (Measurements, 2011; n=605).

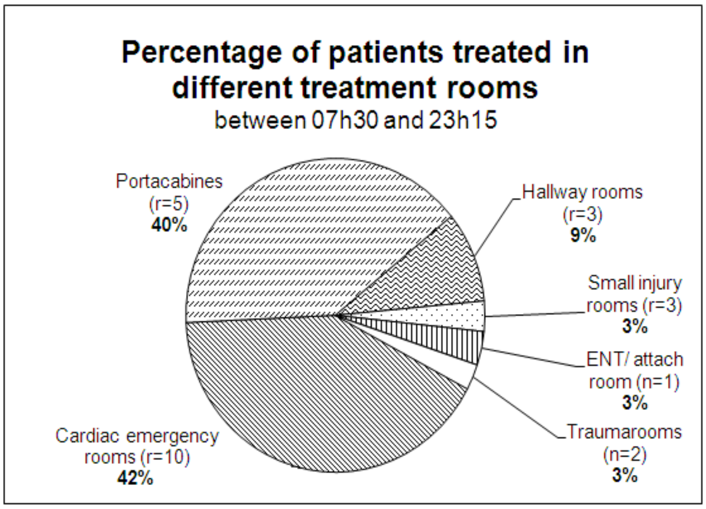

Figure 2.13: Percentage of patients treated in different treatment rooms between 07h30 and 23h15 (Measurements, 2011; n=605).

Based on observations, we conclude that the number of rooms is insufficient in order to place all patients inside a room directly at arrival. Concrete indications for room shortage are the necessity to use hallway beds, all rooms occupied and patients in the waiting room, and situations in which both doctor and patient are waiting for a treatment room to become empty to start the patients treatment (Observations, 2011).

To cope with the problems of treatment room capacity shortage, there lays a possibility in using the ED rooms more efficiently. To explain, let us define the total time a patient spend inside a treatment room (LOS_{ROOM}) as the sum of smaller *legitimate* (T + E) and *illegitimate time* (N) *intervals* of being in the treatment rooms, see equation 2.1.

(Equation 2.1) $$LOS_{ROOM} = \Sigma T + \Sigma E + \Sigma N$$

We define the *legitimate time intervals* as the time intervals a patient is physically under treatment of a doctor or nurse (T), and the time a patient is waiting inside the treatment room with a medical (e.g. the patient needs to be monitored) or social (e.g. patient is aggressive) necessity for waiting inside the room (E). We define the *illegitimate time intervals* as the intervals a patient waits inside a treatment room without a medical or social necessity for waiting inside the room (N). In other words, these patients occupy the treatment room, while they also could wait outside the treatment room, e.g. in the waiting room. Therefore, the treatment rooms can be used more efficiently by reducing, or eliminating, interval *N*. During these periods, the patient keeps a room occupied without a legitimate reason, possibly impairing the access to care of other patients.

One of these periods are the time intervals patients are waiting for their initial doctor contact or contact with a co-assistant after their last contact moment with a nurse. In Figure 2.14, we provide an overview of the times patients were waiting during the 7 days measurement, displayed as the percentage of patients that waited a specific time interval. E.g. 56% of all patients seen on the low care area had their initial contact with a co-assistant or doctor within 5 minutes after the nurse finished, and 32% on the medium/high care area.

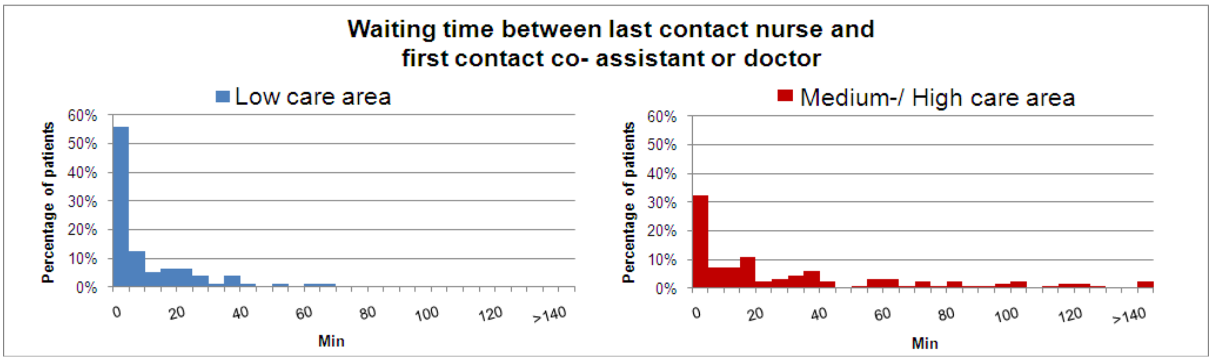

Figure 2.14: Waiting times between last contact nurse and first contact co-assistant or doctor (Measurements, 2011; Low care area, n=79; Medium-/ High care area, n=136).

Although we do not know the percentage of patients belonging to category E or category N, based on conversations with ED physicians and nurse we believe 80% of the patients treated on the low care area and 30% to 50% on the medium/high care area belongs to category N, meaning that they could have waited outside the treatment room until a doctor was ready to see them. Especially for patients who occupy a treatment room for a long time, e.g. 2.9% of the patients on the medium/high care area waited 55 to 60 minutes for their initial co-assistant or doctor treatment, letting these patients wait outside the treatment room benefits during moments of crowding.

DF_{11} Patients wait inside their treatment room for a co-assistant or doctor, after the nurse anamnesis is finished. Besides their undesirable waiting time, they might also impair the access to care of other patients.

Usage of hallway beds

Hallway beds are used when all treatment rooms are occupied and a patient needs to be placed in a bed. These patients are commonly the non-ambulance arrivals who are taken directly to a bed after registration (e.g. when they are in a lot of pain) and the ambulance arrivals, who are never placed inside the waiting room. However, hallway beds are occasionally also used for patients who have been waiting for a long time in the waiting room (Observations, 2011).

We conclude that the presence of patients in hallway beds is highly undesirable, for two reasons:

1) Patients in hallway beds decrease the productivity of staff by 'disturbing' them with questions. When e.g. a patient (or often one of their family members or friends) want to know if the lab results are already available, any person in a white coat passing by will be disturbed. We observed that especially patients who are already irritated can cost several minutes of providing information and explanation, possibly causing a delay for another patient and being a major cause of frustration under staff (Interviews, 2011). We also believe that the mind set of staff is negatively influenced by patients in hallway beds, caused by a more chaotic sphere and constant being remembered that the ED is crowded.

DF_{12} Productivity of staff decreases as patients or patients guests 'disturb' them with questions.

2) The usage of hallway beds results in patients being relocated. By relocating patients, time of staff is wasted and the relocating activity in itself adds no value to the patient either. When it is perceived that a patient definitely needs to be placed inside a treatment room, e.g. for monitoring, another patient is relocated from his room to the hallway. Besides the unfriendly gesture towards the patient that is moved to the hallway, time is wasted by first explaining this patient the situation and, second, by actually relocating the patient. In addition, a patient can also be moved from a hallway bed to a treatment room due to privacy needs of the patients. We observed that residents cannot perform their physical examination in the hallway, e.g. because the patient had to be undressed.

DF_{13} Time is wasted by relocating patients to and from hallway beds.

2.5.2 Diagnostic tests

In Subsection 2.3.5, we mentioned already that the most commonly performed diagnostic procedures on ED patients are lab tests, X-ray tests, CT-scans, ultra sonograms, and ECGs. In this subsection, we describe the diagnostic tests, determine service times and waiting times, and search for possibilities for improvement.

Laboratory: blood- and urine tests

In 2010, 46.5% of all patients received a blood test and 13.4% of the patients a urine test (SAP, 2010; n=40,541), while during the measurement these percentages are 52.3% and 14.9% respectively (Measurements, 2011; blood n=379; urine n=108). Laboratory tests can be requested on the initiative of a doctor or a nurse. During the measurement, 75.9%[2] of the blood tests and 43.1% of the urine tests were requested by a nurse (Measurements, 2011; blood n=328; urine n=65). When the decision is made by a doctor, the doctor informs a nurse and asks to arrange the request. The nurse collects the samples needed, fills in a request form, places the samples and form in one of the cylinders of the automatic transport system used, and sends the request to the laboratory. The laboratory reports the request when received in their own information system (GLIMS), conducts tests on the samples, and finally, after the results are obtained and verified for release, the results become digitally available in the EPR of the patient. In Figure 2.15 we provide an overview of this process path.

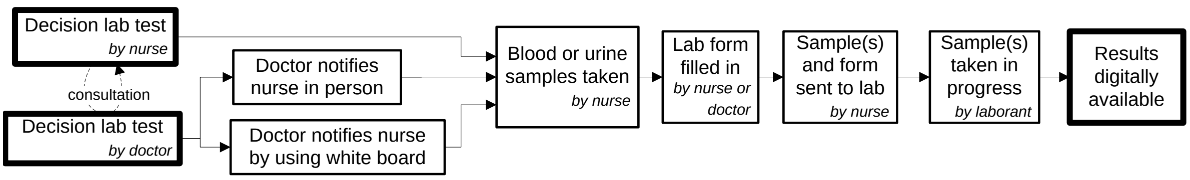

Figure 2.15: Process path request laboratory tests, blood or urine.

Within the process of requesting laboratory tests and obtaining the results, we noticed that the patient LOS often increases due to test results not immediately being used when digitally available (Observations, 2011). The main cause is the unavailability of the doctor at the moment the test results are available, as doctors often start treating other patients while waiting for the diagnostic

[2] *77.1% (Measurements, 2011; n=284) when we only consider the patients arriving during the opening hours of the triage room between 07h30 and 23h15 (see Chapter 5).*

test results, but neither are doctors warn that lab tests are available. The doctor has to check once in a while whether the test results are already available by opening the patients EPR.

DF$_{14}$ Laboratory test results are not immediately used when available.

Also are tests values not always available within the 45 minute norm (Huishoudelijk reglement SEH, 2010, p.16). We distinguish between the moment the final blood or urine value of one request is available in the EPR and the moments individual blood or urine values within one request are available in the EPR (GLIMS, 2011). This distinction is made, as we observed that doctors often start preceding activities while not all test values are available. We provide the results in Figure 2.16 and Figure 2.17. To calculate the duration times before the test results are digitally available in the EPRs, we included 3.5 minute before results become available in the EPR after being approved for release. The computer system used at the lab works with a 7 minutes loop that checks whether results can be released, so on average, results become available after 3.5 minutes after approval for release (Interviews, 2011).

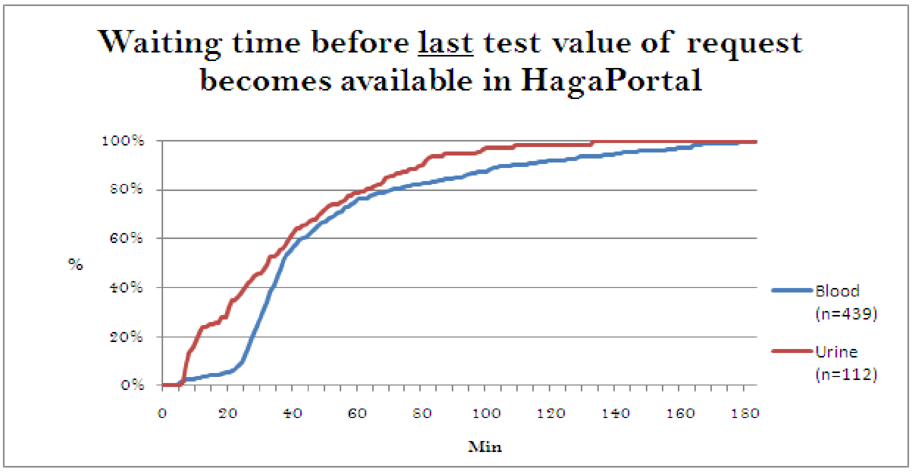

Figure 2.16: Waiting time before last test value of diagnostic lab request becomes available in HagaPortal (Measurements, 2011).

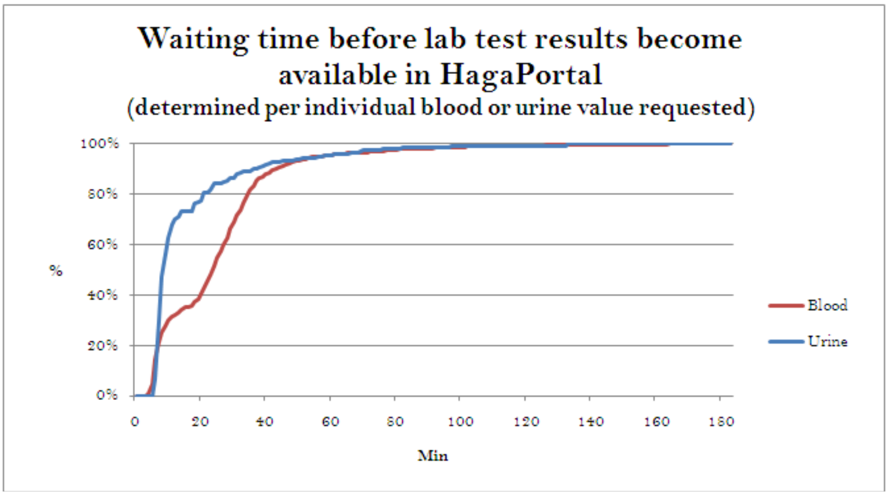

Figure 2.17: Waiting time before lab test results become available in HagaPortal (Measurements, 2011), determined per individual blood (n=10,625) and urine (n=1,370) value requested (GLIMS, 2011).

From Figure 2.16, we conclude that in 65.6% and 69.6% of the requested blood- and urine tests respectively all requested values of one request are available within 45 minutes, while the 80% percentile lies at 67 and 59 minutes. From Figure 2.17, we conclude that in 91.2% and 93.1% of the individual blood- and urine values respectively are available in 45 minutes. But as most often the last blood values available are important to set the diagnosis of a patient (Conversation ED physician, 2011), we place our conclusions upon Figure 2.16 and derive DF_{15}.

DF_{15} Both patient and doctor need to wait for lab test results. 65%-70% of the laboratory tests are available within the 45 minute norm.

Electrocardiogram

Patients under suspicion of suffering from cardiac problems receive an ECG. In 2010, 31.3% of the patients received an ECG (SAP,2010; n=40,541). The decision to make an ECG can be made by either a doctor or a nurse. In 81.7% of the decisions, this decision was made by a nurse (Measurements, 2011; n=218). The ED has two portable ECG devices and the ECGs are made by the nurse treating the patient. We provide an overview of the process path in Figure 2.18.

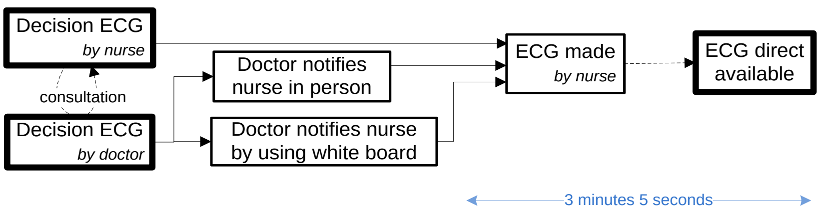

Figure 2.18: Process path request and making electrocardiogram.

The average duration of making an ECG, measured from the moment the nurse takes an ECG device until having the result printed, is 3 minutes and 5 seconds (Measurements, 2011; n=38; σ=43s; CV=0.23). The time between the decision made and the start of making the ECG is unknown.

X-ray test

29.1% of the patients attending the ED receive an X-ray (Measurements, 2011; n=724). The decision to make an X-ray picture is made by a doctor. There is one exception as nurses are allowed to request a specific hand-feet X-ray test, but we leave this test out of our scope. The X-ray tests are made on the ED in a special radiology room, referred to as *X-ray room*, by a technician of the radiology department. When a doctor has decided that an X-ray test is needed, a request form is filled in, the form is signed by the doctor, and placed in a basket at the X-ray room.

Depending on the number of requests, the technician either immediately notifies that the patient can be brought to the X-ray room, or otherwise, the nurse is called by the technician when the patient is next in line. The patient is brought to the X-ray room by a nurse or logistical employee. Once the picture is made, the technician checks the picture on quality, approves the picture, and brings the patient back to the treatment room, while the picture becomes digitally available in the EPR. In Figure 2.19, we provide an overview of the process path and the durations of different activities within the process.

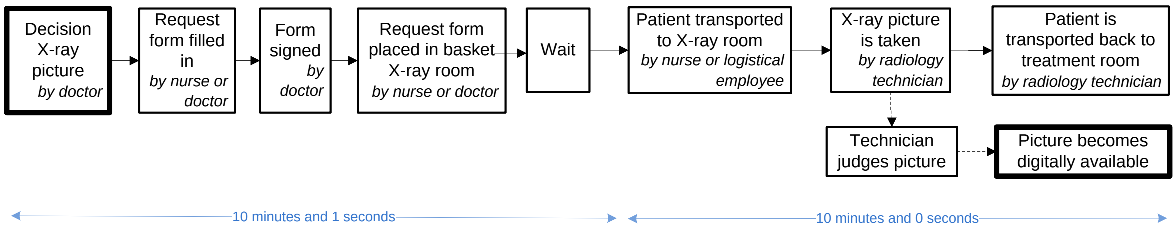

Figure 2.19: Process path request and making X-ray photo.

The service time of an X-ray test, measured from the moment a patient leaves the treatment room until the patient is back in the treatment room, is on average 10 minutes and 0 seconds (Measurements, 2011; n=131; σ=6m59s; CV=0.70). The duration of the activities performed before the patient is brought to the X-ray room fluctuates over time. We provide an overview of the duration between the moment the decision was made and the moment the patient was brought to the X-ray room in Figure 2.20.

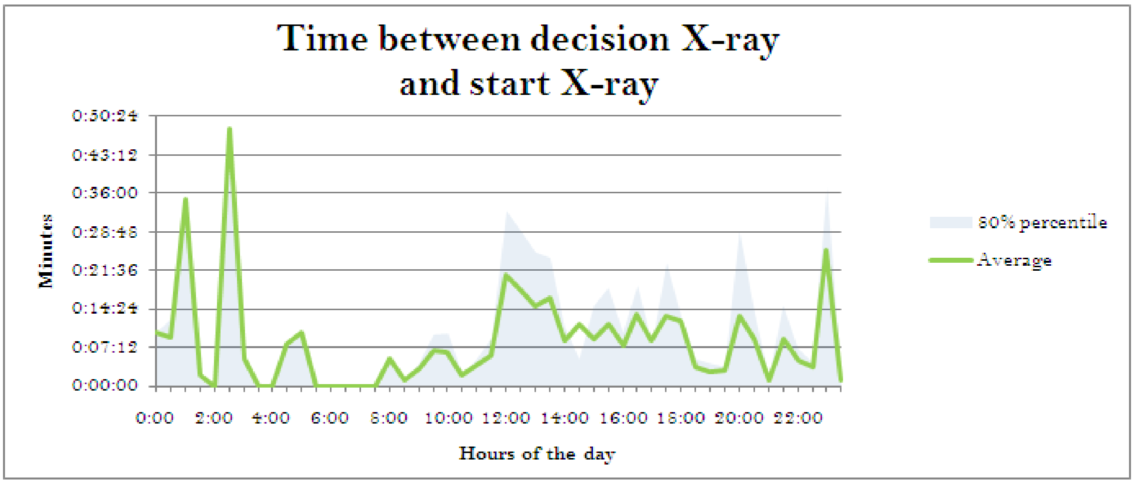

Figure 2.20: Waiting time for X-ray tests during in office hours (Measurements, 2011; n=160).

The overall average duration between decision and transport to the X-ray room is 10 minutes and 1 seconds (n=160; σ=13m01s). However, in Figure 2.20, we see that there are high peaks during the nightly hours, and an increased duration between 12h00 and 14h00, and between 23h00 and 23h30. None of these findings are surprisingly. First, at night the X-ray technicians serve both patients at the ED and inpatients laying in the hospital. Therefore, the technician is not always present and needs to be called when a picture is needed. If the technician is working on e.g. one of the wards, we determined that the waiting time can increase to more than 45 minutes. Second, the increased time between 12h00 and 14h00 is believed to be caused by the lunch breaks of both nurses and X-ray technicians. The nurses normally bring patients to the X-ray room, while one of the technicians transports the patient back to their room. During in-office hours (08h00-16h30) two technicians are assigned to the ED, cooperating to achieve a high turnover. One technician transports a patient back, while the other prepares the next patient. During the lunch breaks of the technicians, from 12h15 to 12h45 and from 13h00 to 13h30, only one technician is available, performing all activities by him-/herself. However, also a shortage in staffing capacity of nurses delays the process between 12h00 and 14h00. We observed that both patient and X-ray technician were waiting, as no nurse was available to bring the patient to the X-ray room (Observations, 2011). Conversations with two technicians reveal that it depends on the initiative of the technicians whether they actually stay waiting for the patient, or get the patient themselves (Interviews, 2011). The third increase visible in Figure 2.20, between 23h00 and 23h30, is believed caused by the 10 a 15 minute period in which the night shift of the nurses take over the day shift. During this period, the nurses carry over their patients and no physically actions are taken during this period.

DF_{16} Patients are not transported to the X-ray room, while the X-ray room is idle and patients are waiting for an X-ray.

DF_{17} Patients wait on average 10 minutes and 1 seconds before being taken for an X-ray, for which we identified different causes: (1) the capacity of the X-ray is insufficient to treat all patients immediately, (2) during out of office hours, the technicians might not directly be available, and (3) during breaks and turnover moments of nursing shifts, the nursing capacity sometimes is short to transport the patients to the X-ray room.

CT-scan or ultra sonogram

7.9% of the patients attending the ED receive a CT-scan and 7.0% an ultra sonogram (Measurements, 2011; n=724). The decision to make a CT-scan or ultra sonogram is made by a doctor. The doctor consults a radiologist to request the test, fills in the request form, and calls the radiology technician to get the test scheduled in the planning of the radiology department. The doctor either immediately receives a time the patient is scheduled or is called back later when the technician first has to create a place in the schedule. Once the doctor has received a time, the time is written on the white board. Approximately 10 minutes before the patient is scheduled, a nurse or logistical employee transports the patient to the radiology department. When the test is made and approved, the result becomes digitally available, and the patient is transported back to the ED. Depending on the expected duration of the test, the nurse or logistical employee waits at the radiology department during the test (Interviews nurses, 2011), however, there are no general agreements. We provide an overview of the process in Figure 2.21.

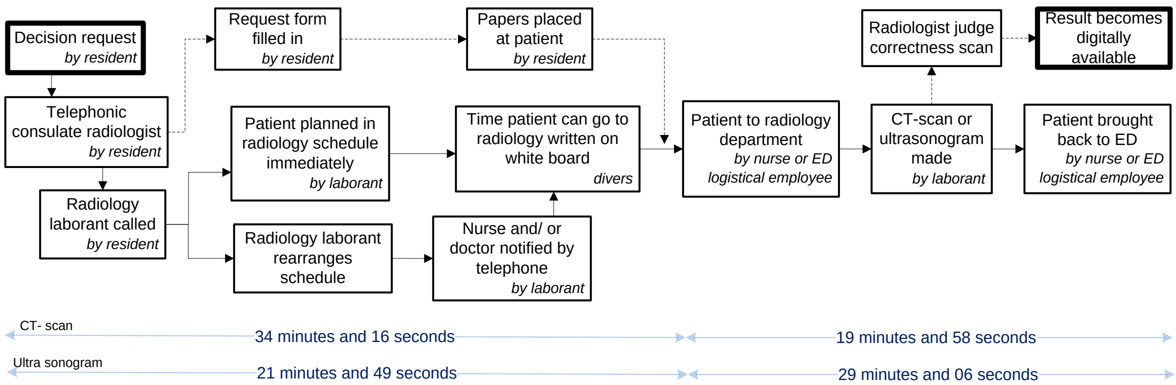

Figure 2.21: Process path request and making CT-scan or ultra sonogram (Measurements, 2011; n= differs).

Patients receive their CT-scans and ultra sonograms at the radiology department. During *in-office hours* during weekdays, the ED patients are online scheduled in the schedule of the radiology by breaking in. The mean service time of a CT-scan, measured from the moment the patient leaves the ED to the moment the patient returns back on the ED, is 19 minutes and 58 seconds (Measurements, 2011; n=34; σ=12m22s; CV=0.62). The mean waiting time, measured from the moment the resident decides to request a CT-scan to the moment the patient leaves the ED, differs between *in-office* hours and *out-of-office* hours of the radiology department. Between 08h00 and 18h00 the mean waiting time is 34 minutes and 16 seconds (Measurements, 2011; n=23; σ=29m30s; CV=0.86), while 24 minutes and 51 seconds (Measurements, 2011; n=20; σ=21m33s; CV=0.87) during the *out-of-office* hours.

By investigating the causes of the waiting times, we identify two factors. First, during *in-office* hours the CT capacity is also used for in- and outpatients. Second, during the *out-of-office* hours, the capacity has also to be shared with other inpatients, while the delay can also be caused by no technician being available. Between 18h00 and 01h30 two technicians are available in the hospital, and between 01h30 and 08h00 only one. During these hours, the technician(s) serve both inpatients from wards, on the intensive care, operating rooms, as well emergency patients in need of an X-ray on the ED or CT-scan at the radiology department. Therefore, it might be that the technician is not directly available.

DF_{18} Patients wait on average 34 minutes and 16 seconds between 08h00 and 18h00 (CV=0.86), and 24 minutes and 51 seconds outside these hours (CV=0.87) for a CT-scan.

The mean service time, measured from the moment the patient leaves the ED to receive an ultra sonogram until returning back, is 29 minutes and 6 seconds (Measurements, 2011; n=28; σ=11m54s; CV=0.41). Further, the mean waiting time is approximately the same during in-office hours and out-of-office hours, namely 21 minutes and 49 seconds (Measurements, 2011; n=21; σ=24m33s; CV=1.13) and 21 minutes and 0 seconds (Measurements, 2011; n=15; σ=19m35s; CV=0.93) respectively. In here, we determined the in-office hours as the hours in which outpatients are scheduled, being from 08h00 to 12h00 and 13h30 to 17h00. From 12h00 to 13h00 is used as *slack* and lunch time, while between 13h00 and 13h30 the radiologist and their residents have education.

We distinguish three causes of these waiting times. First, during *in-office* hours the ultra sonogram capacity is also used for in- and outpatients. Second, between 12h30 and 13h30 patients likely have to wait a long period, as with this hour the radiologists have lunch and education. And third, between 18h00 and 08h00 on weekdays, as well as during the weekends, no radiologist is available. During these hours the radiologist must be called from home to make the ultra sonogram.

DF_{19} Patients wait on average 21 minutes and 49 seconds (CV=1.13) between 08h00 to 12h00 and 13h30 to 18h00 for a ultra sonogram, and 21 minutes and 0 seconds (CV=0.93) outside these hours.

2.5.3 Staffing capacity

A balanced staffing level, in which staffing patterns match demand is essential to minimize medical risks, maximize staff and patient satisfaction, and control staffing costs (Ozcan, 2009; Paul, Reddy, DeFlitch, 2010). In this section, we investigate the fit between capacity and demand, for which we use two methods.

Method 1 The first method we use is determining the percentage of patients who had their initial doctor contact within the maximum allowed waiting time set by triage.

Method 2 A commonly used method to determine the fit between available staffing capacity and demand is comparing the number of staff available towards the number of patients on the ED (Green, 2007). This is an indicator of the amount of work that needs to be done, which in the industry is referred to as *work in progress* (WIP) levels. The WIP levels provide an indication of the workload of different staff members, and we use equation 2.2 to calculate these WIP levels (X_{ijk}).

(Equation 2.2) $$X_{ijk} = X_{ij(k-1)} + A_{ijk} - D_{ijk}$$

In equation 2.2. we define X_{ijk} as the WIP level of specialty *i,* on day (on group of days) *j*, within hour *k*, with e.g. k=13 representing the hour 13h00 to 14h00. $X_{ij(k-1)}$ represents the patients of specialty *i,* on day *j*, who are present on the ED at the beginning of hour *k.* A_{ijk} represents the patients who arrive for specialty *i,* on day *j*, within hour *k*, and D_{ijk} are the patients of specialty *i,* on day *j*, who depart in hour *k.*

We demarcate our 'staffing capacity analysis' to the availability of doctor capacity of the four largest specialties and the availability of nurse capacity. The four largest specialties are the *general surgery, internal medicine, cardiology* and *neurology*, who together take care of 89.2% of all patients (SAP, 2010; n=40,541). Residents working for these four specialties are available at the ED 24 hours a day, while the residents of four other specialties are only present on specific days or are called when a patient arrives, see Table 2.6.

Specialty	**Time interval**	**Comments**
Urology	08h00 - 16h30	During out of office hours (16h30 - 08h00) patients of the urology are first taken care of by the resident of the general surgery and only when necessary the resident of the urology is called.
Hematology	08h00 - 16h30	During out of office hours (16h30 - 08h00) patients of the hematology are taken care of by the resident of the internal medicine.
Orthopedic medicine	24/7 ***Exception*** Tuesdays: 08h00 - 23h00 Thursdays: 08h00 - 18h00	On Tuesdays and Thursdays the orthopedic medicine holds the gate function of the ED. During these hours, at least one resident of the orthopedic medicine is available at the ED.
Pulmonary	24/7	

Table 2.6: Availability of residents on call.

2.5.3.1 Doctor capacity

We start with investigating the fit between capacity and demand using *method 1* for all four specialties, and continue the analysis using *method 2* for all four specialties.

Method 1: Initial doctor contact

To determine whether the initial doctor contact of patients at the ED is within the norms set by triage (see Subsection 2.2.3), we want to judge the four largest specialties on the five triage scales. However, dividing the patients treated during our measurement towards these subgroups reveals that the samples become too small to derive reliable conclusions from.

Therefore, we decide to use the data of 2010 from the EPRs and use our measurement to correct these data for inaccuracies (Observations, 2011). During the measurement we determine that 54%

(n=230) of the initial doctor contact times registered are inaccurate, in which we defined *inaccurate* as a difference larger than or equal to 5 minutes between actual initial doctor contact measured during the measurement and initial doctor contact registered in the EPR (Measurements, 2011; n=428). 25% of the patients had their initial doctor contact earlier than the time registered in the system, with an average of 26 minutes and 39 seconds (Measurements, 2011; n=108), while in 29% the time registered in the system was earlier than the actual initial doctor contact, with an average of 24 minutes and 2 seconds (Measurements, 2011; n=122). We assume these findings are representative for the inaccuracies in the data of 2010 as well, and approximate the upper bound of the percentage of patients having their initial doctor contact within the maximum allowed waiting time set by triage. This is achieved by subtracting 26 minutes and 39 seconds of all registered moments of initial doctor contacts. This approximated upper bound provides an indication of the best possible performance of the ED towards initial doctor contact, meaning that in reality the percentage of patients having their initial doctor contact within the target time can only be as good as the upper bound or worse (i.e. best case scenario). In here we exclude the patients who are triaged as *immediate*, as a target time of 0 minutes can never be met, as well as the urgency groups with a sample size smaller than 20 patients. Table 2.7 provides an overview of the findings, divided towards specialty and different urgency category of the MTS (SAP, 2010). In the last column, we also provide the averages found during our measurement. Note that these percentages are not divided toward specialties.

Urgency	**Max. waiting time** (min)	**Specialty** Gen. surgery	Int. medicine	Cardiology	Neurology	**Measurement** (2011)
Immediate	0	*Excluded*	*Excluded*	*Excluded*	*Excluded*	*Excluded*
Very urgent	10	*64%*	*41%*	*39%*	*54%*	*19%*
Urgent	60	*85%*	*68%*	*68%*	*74%*	*69%*
Standard	120	*97%*	*87%*	*87%*	*95%*	*95%*
Not urgent	240	*100%*	*100%*	*Excluded*	*Excluded*	*Excluded*

Table 2.7: Upper bounds of percentage of patients seen within maximum set waiting time by triage (SAP, 2010; n=31,513).

Based on a comparison of the approximated upper bounds calculated (column 3 to 6) with the percentages found during our measurement (column 7), we conclude that there is no reason to assume that our approximate upper bounds are unreliable. Therefore, we also conclude that the ED is poorly performing in terms of time to initial doctor contact. Even in the best case scenarios the maximum set waiting times are often not met by the four largest specialties for the urgency categories *very urgent, urgent* and *standard.* The *cardiology* performs worst, followed by the *internal medicine*, *neurology* and the *general surgery* performs best.

Method 2: Comparing capacity availability with WIP levels

In Subsection 2.3.6, we described that doctors handle more patients in parallel. During our measurement we found that residents, ED physicians, and ED physicians in training treat at most three patients in parallel, and nurse practitioners and general practitioners two patients (Measurements, 2011). We use this information to determine the fit between staffing capacity and demand.

We base our analysis on data of 2010 (SAP, 2010; n=40,541). Although we are aware that the registration of the moments patients depart are not completely reliable (see Subsection 2.3.1), the data provides a good indication of the fit between the available capacity and demand, which in combination with information obtained from observations and interviews provide valuable insights.

Internal medicine

We provide an overview of the working shifts of the residents of the internal medicine in Table 2.8. Although we provide in Table 2.8 that the evening shift starts at 17h00, depending on the crowding level on the ED, the evening shift can also start at 15h00 or 16h00. The resident working on the day shift calls the resident for the evening between 13h00 and 14h00 to verify whether early additional capacity is believed being necessary, and if not, the resident starts at 17h00. At 17h30 the two residents working the day shift leave the ED to attend the afternoon report.

Time interval	**Residents available**	
	Weekdays	Weekends
08h30-18h00	2	1
17h00-23h30	1	1
23h30-08h30	1	1

Table 2.8: Working shifts residents general surgery.

The residents of the internal medicine take care of 14% of all patients treated at the ED (SAP, 2010; n=40,541). These are the patients who are assigned to *internal medicine*, *gastroenterology, rheumatology* and patients for the *hematology* during out of office hours between 16h30 and 08h30.

In the Figures 2.22 and 2.23, we plot the average WIP levels against the available capacity of internal medicine residents for weekdays and weekends respectively. The left y-axis represents the number of patients on the ED and the right y-axis the number of patients that the available staff can treat in parallel. To clarify the right y-axis, for example, in Figure 2.22 the number of patients that can be served by the capacity available between 12h00 and 13h00 is six, as two residents are available and both are able to treat three patients in parallel. The dotted line in Figure 2.22 represents the additional capacity available, which can be obtained when the resident of the evening shift is called and ask to start earlier.

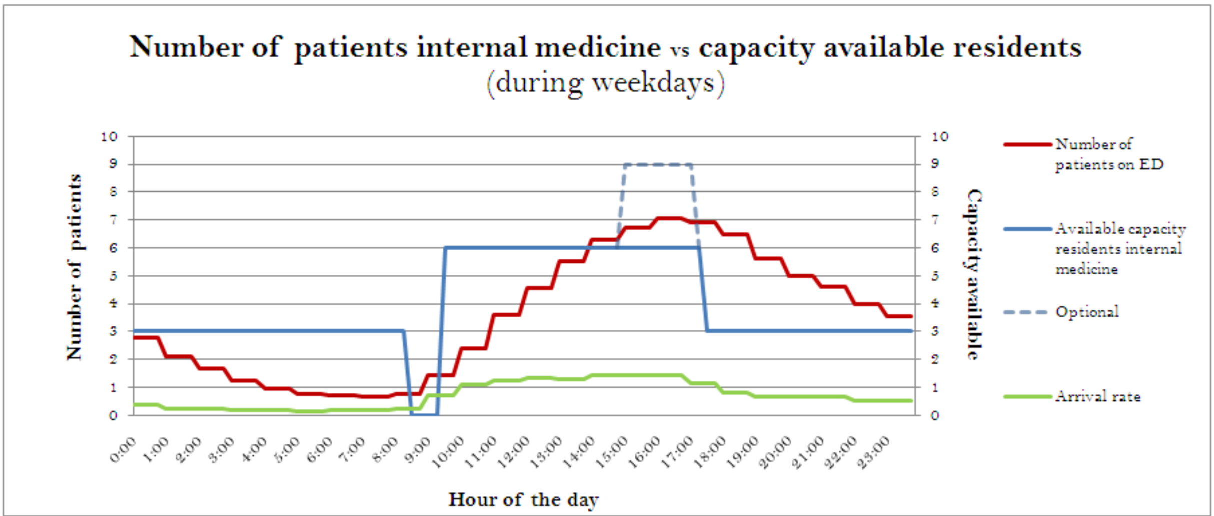

Figure 2.22: Number of patients for the internal medicine per hour of the day versus the available capacity of residents during weekdays (SAP, 2010; n=4,418), where 'capacity' is the number of patients that can be treated by the residents of the internal medicine available (one resident can treat three patients in parallel).

From Figure 2.22, we derive that the number of residents does not fit demand optimally on weekdays. Between 0h00 en 08h30 the resident available could handle more patients than the patients present, as well as the two residents available between 09h15 and 13h30. Further, between 08h30 and 09h15 there are no residents available due to their morning report and radiology meeting. Patients who arrive between 08h30 and 09h15 have to wait before a resident is available, an delay we also noticed during observations. The WIP levels also exceed the number of patients that the available residents can serve in parallel between 17h30 and 0h00. This finding is supported by the residents of the internal medicine, who indicate that they experience high levels of workload in the beginning of their evening shifts (Interviews, 2011), as well as we observed that the residents of the day shift often stay longer to help their colleague of the night shift in the begin of the evening.

In terms of possibility for improvement, we believe the *overcapacity* between 9h15 and 13h30, and the *undercapacity* between 17h30 and 0h00 provide the best options. The *overcapacity* during the night is not of interest, as this capacity is provided by one resident.

DF_{20} Capacity and demand of the internal medicine do not fit optimally during the weekdays, with *overcapacity* between 09h15 and 13h30 and *undercapacity* between 17h30 and 0h00.

Now that we analyzed the fit during the weekdays, let us consider the days of the weekend. During the weekends there are no morning reports or radiology meetings. Also, only one resident is available 24/7 and the average number of patients is much lower. We provide an overview of the fit between capacity and demand in Figure 2.23.

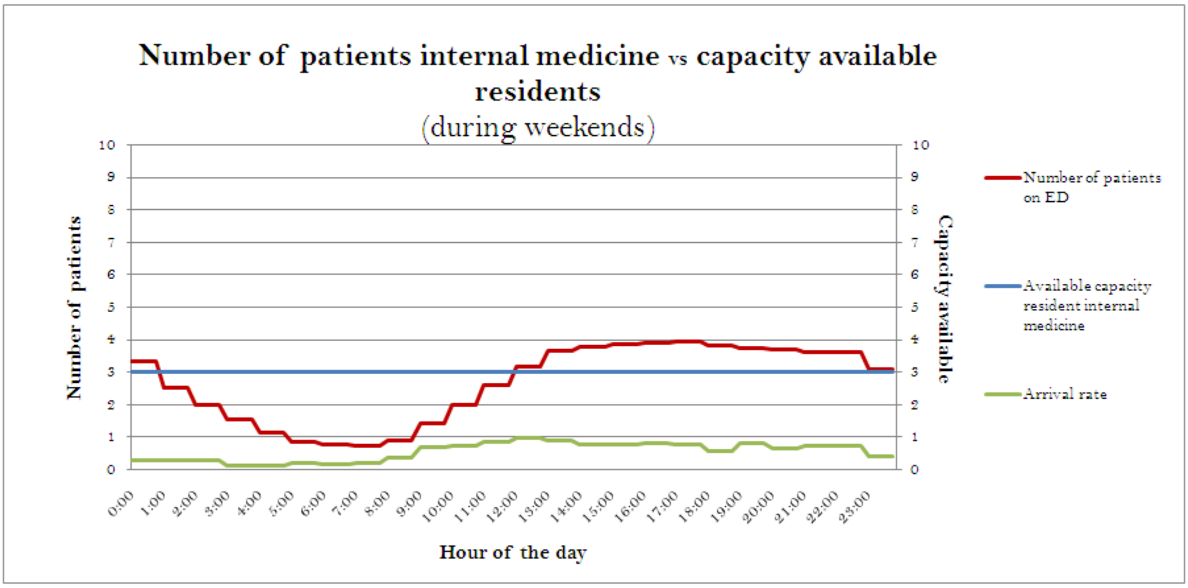

Figure 2.23: Number of patients for the internal medicine per hour of the day versus the available capacity of residents during weekends (SAP, 2010; n=1,382), where 'capacity' is the number of patients that can be treated by the resident of the internal medicine available (one resident can treat three patients in parallel).

From Figure 2.23 we derive that the availability of internal medicine residents during the weekends does not fit the demand optimally. There is *overcapacity* between 01h00 and 12h00, while *undercapacity* between 13h00 and 23h00.

However, despite the misfit, we believe there is no need to change the availability of residents of the internal medicine during the weekends. Although there is *overcapacity* during the nightly hours, this capacity is provided by one resident and working with fractions of staff is not possible. Further is the misfit during the identified hours of *undercapacity* relative small, and staff indicates that commonly the capacity during the weekends is sufficient (Interviews, 2011).

Cardiology

The residents of the cardiology take care of all ED patients assigned to *cardiology, intervention cardiology,* and *cardiopulmonary surgery*, who together represent 14% of all patients treated at the ED (SAP, 2010; n=40,541). In Table 2.9, we give an overview of the work shifts of the residents of the cardiology. During each hour of the day one resident is available at the ED.

Time interval	Residents available
09h00-17h30	1
17h30-23h00	1
23h00-09h00	1

Table 2.9: Working shifts residents cardiology.

The cardiology uses a rule that when five or more patients are available at the ED, an additional resident can be called for 'back-up'. The only drawback of this mechanism is that the additional resident works at the outpatient clinic and is often not available. Based on interviews with residents of the cardiology, ED physicians and nurses, and additionally strengthened with observations of two requests for back-up and both times no resident was available, we conclude that this *back-up mechanism* of the cardiology is not working well.

DF$_{21}$ The 'back-up' resident of the cardiology is not always available.

We provide an overview of the number of patients for the cardiology and the availability of capacity in the Figures 2.24 and 2.25, for weekdays and weekends respectively. The capacity of the back-up resident are not included, for two reasons. First, we believe that fixed capacity should fit demand without additional capacity of the back-up resident. And second, the resident is often not available.

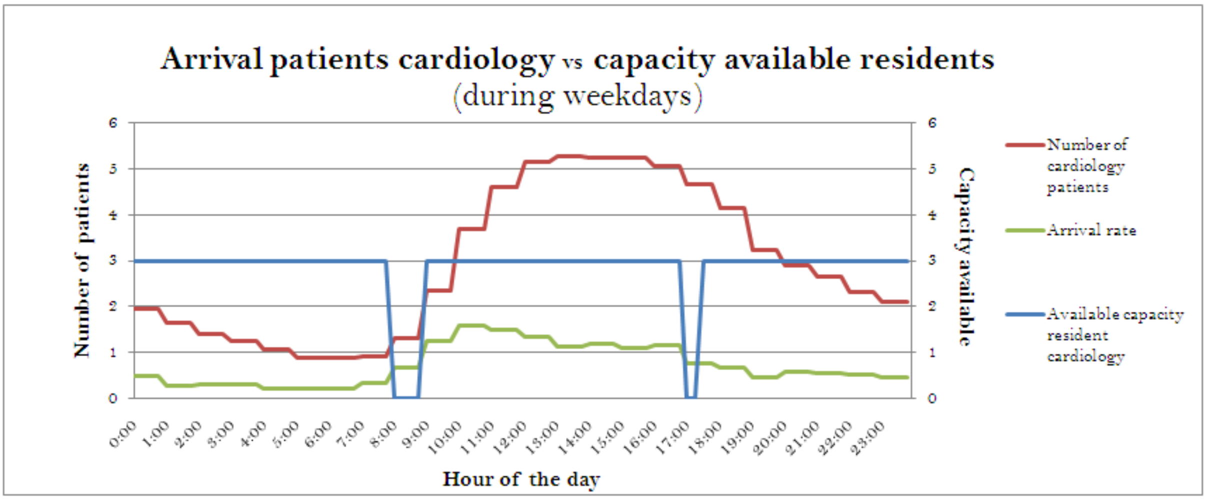

Figure 2.24: Number of patients for the cardiology per hour of day versus the available capacity of residents during weekdays (SAP, 2010; n=4,515), where 'capacity' is the number of patients that can be treated by the resident of the cardiology available (one resident can treat three patients in parallel).

From Figure 2.24, we derive that the available capacity of cardiology residents does not fit the demand optimally. Between 08h00 and 09h00, and between 17h00 and approximately 17h30 there is no resident available at the ED due to the morning- and afternoon reports respectively. Especially the afternoon report is undesirable, due to the high number of patients being present on the ED. Figure 2.24 also indicates that the cardiology suffers from *undercapacity* between 10h00 and 20h00, a finding that correspond with the perceptions of nurses and ED physicians. They indicate that of the residents available most often the resident of the cardiology has the highest workload and causes delays in throughput process by lack of capacity available (Interviews with three ED physicians and five nurses, 2011). Considering the *overcapacity* visible between 20h00 and 08h00 there is no possibility for improvement, as the capacity is provided by one resident.

DF_{22} Capacity and demand of the cardiology do not fit optimally during the weekdays, with *undercapacity* between 10h00 to 20h00.

During the weekends both the capacity and demand differ compared to the weekdays. There are no report moments and the average number of patients attending the ED for the cardiology is lower. In Figure 2.25 we provide an overview of the weekend days.

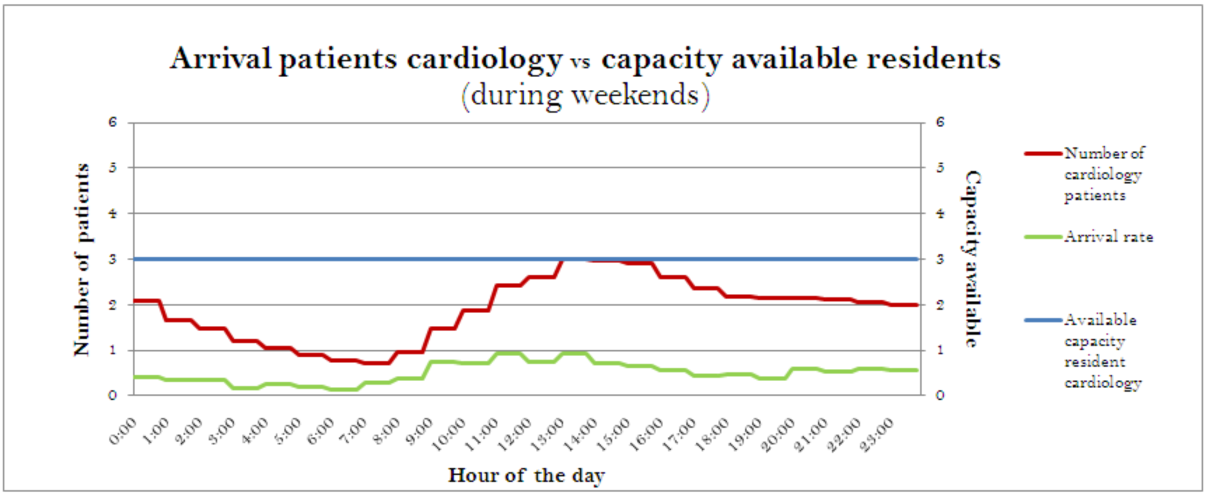

Figure 2.25: Number of patients for the cardiology per hour of the day versus the available capacity of residents during weekends (SAP, 2010; n=1,258), where 'capacity' is the number of patients that can be treated by the resident of the cardiology available (one resident can treat three patients in parallel).

Considering the available cardiology capacity in the weekend, we derive from Figure 2.25 that capacity does not completely fit demand during the weekends. During most hours of the day there is *overcapacity*, but as the capacity is provided by one resident, there is no possibility for improvement.

Neurology

We provide an overview of the work shifts of residents of the neurology in Table 2.10. At all time, one resident of the neurology is available. They take care of the ED patients assigned to *neurology* and *neuro-surgery*, who together represent 7% of all patients treated at the ED (SAP, 2010; n=40,541).

Time interval	Residents available
08h30-17h00	1
15h00-23h00	1
23h00-08h30	1

Table 2.10: Working shifts residents neurology.

We provide an overview of the available staff capacity versus the number of patients attending the ED for the neurology in the Figures 2.26 and 2.27, for the weekdays and weekends respectively.

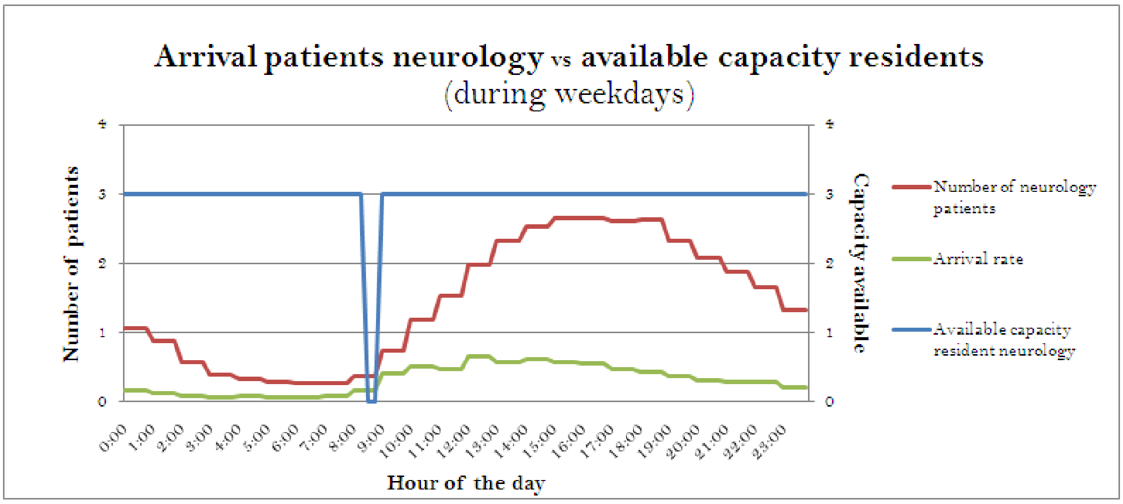

Figure 2.26: Number of patients for the neurology per hour of the day versus the available capacity of residents during weekdays (SAP, 2010; n=2,031), where 'capacity' is the number of patients that can be treated by the resident of the neurology available (one resident can treat three patients in parallel).

From Figure 2.26, we derive that the available capacity of neurology residents does not completely fit demand, as during the morning report there is no resident available between 08h30 and 09h00. However, due to the short period of time and the low number of patients in the system, we believe that the delay caused by the absence of a resident during the morning reports is very small and does not need additional attention. Further, there is no possibility for improvement in terms of using capacity more efficiently, as the capacity is provided by one resident.

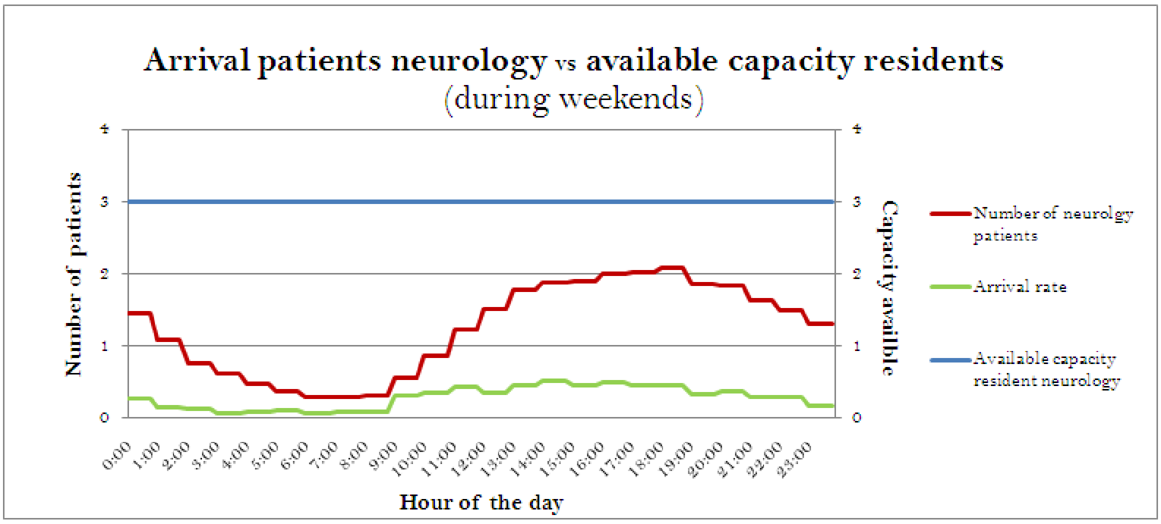

Figure 2.27: Number of patients for the neurology per hour of the day versus the available capacity of residents during weekends (SAP, 2010; n=715), where 'capacity' is the number of patients that can be treated by the resident of the neurology available (one resident can treat three patients in parallel).

During the weekends there are no reports, the average WIP level is relative low, but with only one resident working there is no possibility for improvement.

General surgery

In Table 2.11, we provide an overview of the working shifts of the residents of general surgery. The residents of the general surgery take care of ED patients assigned to *general surgery*, *pediatric care, plastic surgery, dermatology, urology* (during out of offices hours between 16h30 and 08h30), and self referring patients of whom the specialty is not clear at arrival (general surgery holds 'the gate function'[3]). This group represents 54% of all patients treated at the ED (SAP, 2010; n=40,541).

Time interval	Residents available
08h30-17h00	1
17h00-23h30	1
23h30-08h30	1

Table 2.11: Working shifts residents general surgery.

Besides the resident present on the ED, a second 'back-up' resident is available. This resident works on the outpatient clinic, operating room or one of the wards, and can be called during moments of crowding. However, conversations with residents and ED physicians reveal that this mechanism is not always working well for two reasons. First, a 'back-up' resident is not always available, e.g. because they are helping in an operating room. And second, sometimes a *youngest* resident is send to the ED as back-up. Although now an additional pair of hands are present at the ED, the throughput is not increasing as this doctor is commonly inexperienced and needs a lot of supervision and consultations.

DF_{23} The 'back-up' resident of the general surgery is not always available. Also the *youngest* resident can be send as back-up with the possible result that throughput does not increase when the resident is inexperienced and in need of a lot of supervision and consultations.

Alongside the residents of the general surgery, also ED physicians, ED physicians in training, nurse practitioners (NP), and general practitioners (GP) in training treat patients of the general surgery. The NPs and GPs only treat patients with small injuries on the low care area, whereas the ED physicians also treat patients on the medium and high care areas. In Table 2.12, we provide an overview of the shifts of these doctors. During both the day shift and evening shift, at least two ED physicians in training, NPs, or GPs are available ($X1 + X2 + X3 \geq 2$ and $Y1 + Y2 + Y3 \geq 2$), while sometimes even three. This occurs when all shifts during the month are filled with one doctor and the remaining contractual hours are spread. This extra capacity is first assigned to Monday and Friday evening shifts, as these are believed being most crowded, followed by other shifts during the week. In Section 2.2, we determined that the Mondays and Fridays are indeed the most crowded.

Shift	Time interval	ED physicians	ED physicians in training	NPs	GPs in training
Day	08h00-18h00	1			
	07h30-16h30		X1		
	07h30-15h30			X2	X3
Evening	13h00-23h00	1			
	14h00-23h00		Y1	Y2	
	15h00-23h00				Y3
Weekend	10h00-20h00	1			

Table 2.12: Working shifts of ED physicians in training, general practitioners in training and nurse practitioners ($X1 + X2 + X3 \geq 2$ and $Y1 + Y2 + Y3 \geq 2$).

[3] *Except on Tuesdays between 08h00 and 23h00 and Thursdays between 08h00 and 18h00 (see Table 2.6).*

In our analysis towards the fit between available staffing capacity and demand for the patients of the general surgery, we do not include the capacity of ED physicians available. The ED physicians point out that their capacity is only meant to be used for non-emergency patient care at moments of crowding, and therefore, we do not include their capacity to determine whether enough capacity is available. According to the ED physicians, they have four tasks (Interviews ED physicians, 2011). Mentioned in sequence of importance, their tasks are: (1) providing care and supervise patients with an immediate care need, (2) supervise residents, ED physicians in training, NPs, GPs, and co-assistants, (3) manage 'logistical activities on the ED', e.g. determine whether a doctor should be relocated from low to medium care, or when a room is required, decide which patient can be placed in a hallway bed etc., and (4) providing care to patients without an immediate care need.

In the Figures 2.28 and 2.29, we provide an overview of the available staffing capacity of the *general surgery* against the average WIP levels during the weekdays and weekends respectively. In both graphs we plotted a minimum and maximum capacity available, which is caused by the different working shifts hours of the doctors, and the difference in the number of patients they can serve in parallel.

The available capacity differs on Tuesdays, from 08h00 to 23h00, and Thursdays, from 08h00 to 18h00, when the orthopedic medicine contains the gate function (see Table 2.6). During these hours both a resident of the orthopedic medicine and a resident of the general surgery are available at the ED, alongside the other ED physicians, NPs and GPs also working. In terms of available capacity, the resident of the orthopedic medicine is extra capacity. The number of patients does not change, only the specialty to which patients are assigned.

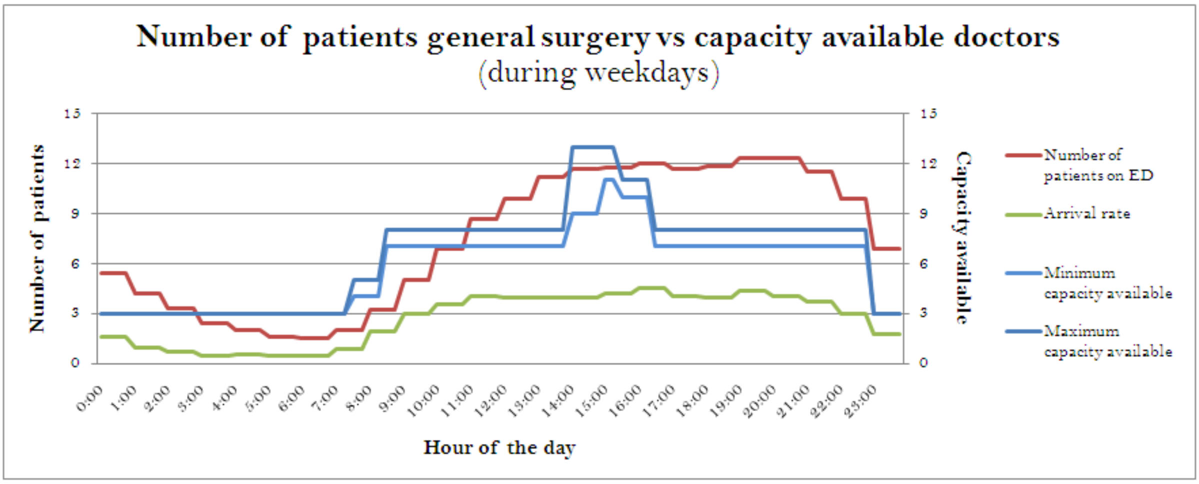

Figure 2.28: Number of patients for the general surgery per hour of the day versus the available capacity of doctors on weekdays (SAP, 2010; n= 16,675), where 'capacity' is the number of patients that can be treated by the doctors working for the general surgery (dependent on the doctor, (s)he can serve 2 or 3 patients in parallel).

From Figure 2.28, we derive that the available capacity does not fit demand optimally. Between 03h00 to 10h00 there is overcapacity, while between 11h00 and 03h00 demand exceeds capacity, except when an ED physicians in training works both the day and evening shift (see between 14h00 and 16h30). The misfit is the highest between 23h00 and 0h00, followed by the period between 0h00 and 02h00, and 16h30 and 22h00. This finding corresponds quite well with the ED physicians and NPs indicating that they perceive the highest workload between 15h00 and 22h00, and nurses indicating that the general surgery often is very busy at the beginning of their night shift. Although there is a difference of 1.5 hours between 15h00 and 22h00, we believe this is caused by the way staff perceives their workload.

DF_{24} Capacity and demand of the general surgery do not fit demand optimally on Mondays, Wednesdays, and Fridays, with the largest mismatch in terms of *undercapacity* between 23h00 and 0h00, followed by the period between 17h00 and 22h00.

Now that we investigated the fit between the doctors working for the general surgery during the weekdays, let us continue with investigating the fit during the weekends, see Figure 2.29.

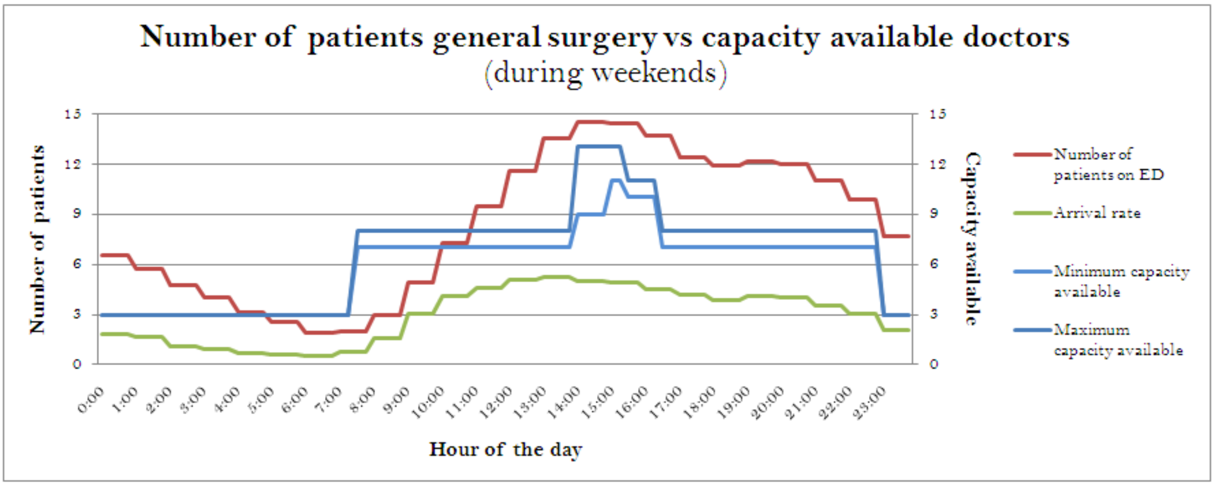

Figure 2.29: Number of patients for the general surgery per hour of the day versus the number of residents available on Mondays, Wednesdays, and Fridays (SAP, 2010; n= 7,408), where 'capacity' is the number of patients that can be treated by the doctors available working for the specialty general surgery.

From Figure 2.29, we derive that the available capacity does not fit demand well during the weekend days. Between 05h00 and 10h00 capacity is likely to be unused, while during the other hours, the available capacity is insufficient. Considering the ratio between available capacity and demand, the largest misfit is found between 23h00 and 01h00, followed by the period between 12h00 and 14h00, and 16h30 to 21h00.

DF_{25} Capacity and demand of the general surgery do not fit during the weekends, with the largest mismatch between 23h00 and 01h00, followed by the periods between 12h00 and 14h00, and 16h30 and 21h00.

2.5.3.2 Nursing capacity

The nurses working at the ED work in six different shifts. We provide an overview of the different shifts and the standard occupancy of nurses working per shift in Table 2.13 (Conversation Bos - department manager, 2011). Between 07h30 to 23h15, one nurse is assigned as *triage nurse* and one nurse is *STIP.*

Shift	Time	Number of nurses working
A: Early	07h30-15h30	4
T: Between	09h30-18h00	2
B: Late	15h00-23h15	5
P: P-shift	12h00-20h00	1
J: J-shift	16h00-00h15	1
D: Night shift	23h15-07h30	4

Table 2.13: Working shift nurses (incl. triage and STIP nurses).

The *STIP* nurse receives patient announcements of ambulances, allocates doctors and the trauma team if necessary, takes ambulance arrivals in by arranging a bed for them, and making a first judgment upon the acuity of the patients care need. The STIP nurse also takes notice of the workload of nurses on the different areas of the ED in order to relocate nursing staff if necessary, takes notice whether patients are 'not forgotten' somewhere on the ED, and encourages residents to call for assistants during moments of crowding (Interviews and observations, 2011). For additional information on the activities of the triage nurse, see Subsection 2.3.3.

In contrary to the doctors, our measurement provides no information upon the number of patients one nurse can treat in parallel. However, by plotting the available nursing capacity towards the WIP levels of patients we obtain insight in whether the capacity and demand generally fit. Based on observations, we determined that the nurses are not the bottlenecks in the throughput process, except during lunch and supper breaks in which we noticed that the throughput processes of patients occasionally stagnated due to insufficient nursing capacity available.

In Figure 2.30, we provide an overview of number of patients on the ED versus the available nursing capacity over different hours of the day. The STIP nurse and triage nurse, who works between 07h30 and 23h15, are not included in the lines presenting the available nursing capacity and, as the number of nurses does not change between weekdays and weekends, we plot the both the weekdays and weekends in one graph.

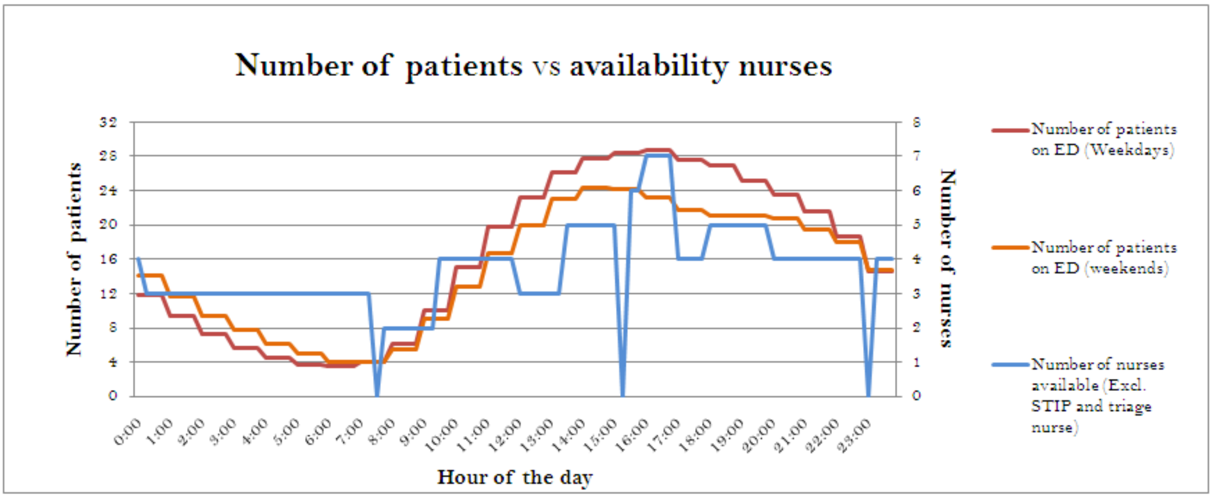

Figure 2.30: Number of patients on the ED versus the actual number of nurses available (SAP, 2010; n=40,541).

In Figure 2.30, we see that during the lunch (between 12h00 and 13h30) and supper breaks (between 17h00 and 18h00) fewer nurses are available to treat or perform activities for patients. The lunch break consists of three shifts of 30 minute breaks, taken by two nurses a shift. Although an additional nurse starts at 12h00 (P-shift), during the lunch break hours the available capacity is lower, while the number of patients on the ED increases. We believe this influences the patient LOS, as e.g. in Subsection 2.5.2 we found that the time before a patient receives their X-ray clearly increases during these hours. Also during suppertime, a gap is seen in Figure 2.30. Where between 14h00 and 15h00 approximately 28 patients are taken care of by five nurses, during supper time between 17h00 and 18h00, the same number of patients have to be taken care of by four nurses.

DF_{26} Treatments of patients are delayed by insufficient nursing capacity available during lunch and supper breaks.

2.5.4 Conclusions 'resources'

Treatment room usage

- The three small injury rooms are normally not used between 07h30 and 23h15, because the nurse assigned to the low care area cannot keep the overview of both patients in the three small injury rooms and patients in the five beds of the portacabines.
- In the current way of working, the number of treatment rooms available is insufficient in order to place all patients inside a room at arrival. A possibility for improvement for both the patient waiting for a treatment room, as well for the patient waiting in the treatment room, is by reducing the time patients wait inside their treatment room for a co-assistant or doctor, after the nurse anamnesis is finished [DF_{11}].
- The usage of hallway beds is highly undesirable.
    - [DF_{12}] Productivity of staff decreases as patients or patients guests 'disturb' them with questions.
    - [DF_{13}] Time is wasted by relocating patients through and from hallway beds.
    - The mind set of staff is negatively influenced due to the chaotic sphere caused by patients and patients guests in the hallways.
    - In terms of patient satisfaction, it is likely that patients prefer being treated inside a treatment room instead of being treated in a hallway.

Diagnostic tests

- 75.9% of the blood tests, 43.1% of the urine tests, and 81.7% of the ECGs are started on the initiative of a nurse, without interference of a doctor (Measurements, 2011; blood n=328; urine n=65; ECGs n=218). CT-scans, ultra sonograms, and X-rays (except one type) are always requested by the doctor.
- [DF_{14} and DF_{15}] The throughput process of patients is delayed when a patient needs a blood or urine test, as the patients treatment often cannot be continued before the results are available. Quantifying the delay, 65%-70% of the laboratory test are available within the 45 minute norm.
  But also when the laboratory test results are available, we determined that the patients treatment is often not immediately continued, with two possible causes:
    - Doctors work *on* more patients in parallel and are not directly available when the test results are available.
    - There is no active audio or visual sign that warns doctors that test results are available.

- [DF_{16} and DF_{17}] The throughput process of patients is delayed when a patient needs an X-ray. Patients wait on average 10 minutes and 01 seconds for an X-ray, for which we identified three different causes:
    - The ED has one X-ray room and the capacity of this room is insufficient to treat all patients immediately. During moments of crowding patients have to wait for each other.
    - During the *out of office* hours (between 16h30 and 08h00) the technicians also serve inpatients from wards and the IC. Therefore, it might be that the technician is not available at the ED and needs to be called. Between 16h30 and 01h30 two technicians are available, resulting most often in one being available at the ED. However, between 01h30 and 08h00 only one technician is present.
    - During breaks and turnover moments of nursing shifts, the nursing capacity sometimes is short to transport the patients to the X-ray room. When this happens, the X-ray room is idle, while patients are waiting for an X-ray.
- [DF_{18}] Patients wait on average 34 minutes and 16 seconds during *in-office* hours (between 08h00 and 18h00) (CV=0.86), and 24 minutes and 51 seconds during *out-of-office* hours (CV=0.87) for a CT-scan. During *in-office* hours the ED patients have to share the CT capacity with other in- and outpatients, while during *out-of-office* hours the main cause is believed being the technician who is not directly available.
- [DF_{19}] Patients wait on average 21 minutes and 49 seconds (CV=1.13) between 08h00 to 12h00 and 13h30 to 18h00 for an ultra sonogram, and 21 minutes and 0 seconds (CV=0.93) outside these hours. During *in-office* hours the ED patients have to share the ultra sonogram capacity with other in- and outpatients, while between 12h30 and 13h30 ED patients likely have to wait due to lunch and education of the radiologists, and in the evenings, nights and weekends patients have to wait as commonly no radiologist is available and must be called from home.

Staffing capacity of doctors

- [DF_{20}] Capacity and demand of the **internal medicine** do not fit optimally during the weekdays. Our analysis of staff availability towards WIP levels reveals that there is *overcapacity* between 09h15 and 13h30, while *undercapacity* between 17h30 and 0h00 (see Figure 2.22). This finding is supported by:
    - Residents indicating high levels of workload in the beginning of their evening shift (Interviews, 2011).
    - Observations reveal that the residents of the day shift often stay longer to help their colleague of the night shift in the begin of the evening.
    - Our analysis of the waiting times to *initial doctor contact*, which reveals that the internal medicine scores second worst (see Table 2.7) and many patients do not receive their initial contact within the set norm for triage.

- [DF_{22}] Capacity and demand of the **cardiology** do not fit optimally during the weekdays, with *undercapacity* between 10h00 to 20h00 (see Figure 2.24). This finding is supported by:
    - ED physicians and nurses who perceive that (of the four largest specialties) the cardiology causes the longest delays in the throughput process by lack of capacity available (Interviews, 2011).

  - Our analysis of the waiting times to *initial doctor contact*, which reveals that the cardiology scores worst on this measure of the four largest specialties (see Table 2.7).
- [DF_{21}] The mechanism used by the **cardiology** of calling a 'back-up' resident is not working well. The 'back-up' resident is not called fast enough, as well as not always available when called. Currently, the control rule used, states that the 'back-up' resident can be called when five or more patients are at the ED. However, as one resident only treats maximally three patients in parallel, the throughput times of at least two patients are delayed.

- To analyze the capacity and demand of the **general surgery** we excluded the available capacity of the ED physicians. The ED physicians point out that their capacity is only meant to be used for non-emergency patient care at moments of crowding, and therefore we do not include their capacity to determine whether enough capacity is available. Within this demarcation we conclude that:
  - [DF_{24}] the capacity and demand of the general surgery do not fit optimally on Mondays, Wednesdays, and Fridays, with the largest mismatch in terms of *undercapacity* between 23h00 and 0h00, followed by the period between 17h00 and 22h00.
  - [DF_{25}] neither do capacity and demand fit optimally during the weekends. During the weekends the largest mismatch is found between 23h00 and 01h00, followed by the periods between 12h00 and 14h00, and 16h30 and 21h00.
- [DF_{23}] The mechanism used by the **general surgery** of calling a 'back-up' resident is not working optimally. The 'back-up' resident is not always available, or the *youngest* resident is send. This resident is commonly inexperienced and needs of a lot of supervision and consultations, with the result that throughput does not increase (Observations, 2011).

Staffing capacity of nurses

- [DF_{26}] There are no indications that the number of nurses available cause delays in patients throughput, except during lunch and supper breaks.

2.6 Future situation

The ED is facing two future changes that alter the patient inflow. First, the ED becomes part of an integrated emergency post, and second, the other emergency department of HagaZiekenhuis located at the Sportlaan is going to be closed for adult emergency care (Prins, 2011). Both changes are planned for May 2012 and influence the patients input and output flow of the ED. In order to define valuable recommendations, we investigate the influence of these future changes on the throughput process of the ED in this section. In Subsection 2.6.1, we analyze the emergency post, and in Subsection 2.6.2, we discuss the closure of ED Sportlaan for adult emergency care.

2.6.1 Integrated Emergency Post

In the integrated emergency post, the ED is going to cooperate with a general practitioner post (GP post) and the AADU. The ED and GP post will be located alongside each other, with the AADU on the floor above them. The entrance, registration desk and waiting rooms are shared. An ED nurse triages all patients using the MTS (see Subsection 2.2.3), and the MTS indicates whether a patient must be assigned to the GP post or the ED. Referred patients are always assigned to the ED, but in case the patient is a self referral, the patient can be assigned to the GP post.

Forecast changes in patient volume

From Subsection 2.2.4, we know that 49.6% of all patients attending the ED are self referring patients. When a large part of this input flow deflects towards the GP post, demand towards ED resources declines, likely resulting in waiting times decreasing when capacity levels remain unchanged. To forecast the changing patient volume of the ED, we use a retrospective analysis (SAP, 2010) based on triage codes and two documents that both indicate whether a patient with a specific triage code can be treated by a GP or must be treated at the ED. The first document is the *MTS complain acuity matrix* (KUM MTS), which is created in England by ED physicians and ED nurses, and provides per triage code whether the patient can be seen by a GP. The second document is an internal document of HagaZiekenhuis, in which per MTS category specialists have determined whether a patient with a specific triage indication can be seen by a GP or must be treated at the ED (KUM HAGA). In our forecast, we also include an estimation that 11% of the patients who are initially seen by a GP are secondarily referred to the ED. This percentage is copied from a study performed in the LUMC (Prins, 2011), a hospital with an urban patient population like HagaZiekenhuis.

The results of our forecast differ a lot between the KUM MTS and the KUM HAGA. Based on the KUM MTS the expected patient volumes attending the ED decrease with 7.1%, while based on the KUM HAGA the expected decrease is 35.6%. To place these percentages in perspective, at the LUMC 33% of the patients attending the ED are referred to the GP (LUMC, 2008, p25), and including 11% send back, results in a production loss of approximately 30%, indicating that the 35.6% is well plausible. We provide an overview of our findings specified towards the largest four specialties in Table 2.14.

	General surgery	**Cardiology**	**Internal medicine**	**Neurology**
SAP, 2010	21,834	5,556	4,559	2,733
Forecast KUM MTS	19,449	5,469	4,398	2,659
Difference	*-10.9%*	*-1.6%*	*-3.5%*	*-2.7%*
Forecast KUM HAGA	10,016	5,223	4,146	2,430
Difference	*-54.1%*	*-6.0%*	*-9.1%*	*-11.1%*

Table 2.14: Forecast ED patient volume changes by opening GP post.

Different number of treatment rooms available

In the emergency post, the composition of treatment rooms changes slightly, as two low care beds will be changed towards two medium care beds (Twynstra Gudde, 2008). There will also be an additional *fast track room*, but the exact way of usage is not yet defined.

Acute assessment and diagnostic unit

The AADU becomes 26 beds instead of the current 16 beds, and patients of all specialties can be admitted on the AADU. In the new situation, patients can only stay for maximum 4 hours at the ED. Once these hours are passed and no treatment plan is established upon the patient, the patient will be transferred to the AADU.

2.6.2 Closure of the ED Sportlaan for adult emergency care

The second change the ED is facing in 2012 is the closure of the ED Sportlaan for adult emergency care. Once closed, the patients have to go to the ED Leyweg or to an ED of one of the competing hospitals in The Hague. De Groot (2010) executed already a research towards the expected changes in patients flows based on patient postal codes, and estimates that 45% of the patients are likely to go to a competing hospital. Using the data of 2010, when 8,675 adults attended the ED Sportlaan (SAP, 2010; included all patients ≥ 16 years old), we estimate that the number of patients attending the ED increases with 4,770 patients (55%). Additionally, including that 75% of the patients in 2010 were self referrals, combined with our finding in the previous subsection that 7.1% to 35.6% of all patients are likely send to the GP (note that approximately 50% are self referrals on the ED Leyweg), we estimate that the patient volume at the ED Leyweg increases with 2,223 to 4,263 patients a year, equal to 6.1 to 11.7 patients a day.

2.6.3 Conclusions 'future situation'

- we predict a decrease in 7% to 36% patient volume, when the IEP is opened.
- the patient volume at the ED Leyweg increases when the ED Sportlaan is closed for adult emergency care, with approximately 6 to 12 patients a day.

2.7 Summary of delaying factors

We started this chapter stating that the purpose of this chapter is to obtain insight in the throughput process and identify and quantify delaying factors in the process causing waiting times. Throughout this chapter, we provided a detailed description of the ED processes, her resources, future patient flows, and identified twenty six delaying factors of which we quantified eleven. In Table 2.15, we provide a structured overview of these delaying factors, in which we also provide the percentage of all patients affected by a specific delay. The other sixteen delaying factors are shown in Table 2.16.

	Waiting for:	**Average waiting time (min)**	**CV**	**Patients affected**
DF_3	Triage nurse	7	0.90	72%
DF_4	Placement in treatment room (after triage)			
	- Low care	25	1.78	34%
	- Medium/ high care	14	1.27	24%
DF_6	Inter collegial consult doctor	24	0.94	… %(A)
	External actors to depart			
DF_8	- Admissions(B)	24	1.25	30%
DF_9	- Ambulance or lay cab	63	0.67	2%
DF_{10}	- Crisis service	98	0.35	1%
DF_{11}	Availability co-assistant or doctor(C)			
	- Low care	10	1.50	46%
	- Medium/ high care(D)	32	1.28	52%
DF_{15}	Laboratory test results			
	- Blood tests	47	0.79	52%
	- Urine tests	36	0.81	15%
	Radiology diagnostic tests			
DF_{17}	- X-ray picture	10	0.70	29%
DF_{18}	- CT-scan(E)	34	0.86	8%
DF_{19}	- Ultra sonogram(E)	22	1.13	7%

(A) Value is unreliable; (B) Between 07h30 and 17h00; (C) Measured from the moment the nurse is finished with the patient; (D) Exclusive patients treated in trauma room 1; (E) Between 08h00 and 18h00.

Table 2.15: Overview of quantified delaying factors (Measurements, 2011).

	Cause of waiting
DF_1	The productivity of staff decreases by increasing levels of frustration and discussion these frustrations, caused by *illegitimate* patients attending the ED.
DF_2	The service time of triage is in 42% longer than the maximum 5 minute norm (NVSHV, 2005).
DF_5	The patient throughput process is delayed when doctors must wait for their consult with a supervisor, or wait for the supervisor to arrive at the ED.
DF_7	Patients treatment is not always started when doctors are at the end of their working shift.
DF_{12}	Productivity of staff decreases as patients or patients guests 'disturb' them with questions.
DF_{13}	Time is wasted by relocating patients through and from hallway beds.
DF_{14}	Laboratory test results are not immediately used when available.
DF_{16}	Patients are not transported to the X-ray room, while the X-ray room is idle and patients are waiting for an X-ray.
 DF_{20} DF_{21} DF_{23} DF_{24}	Shortage of doctors capacity of: - internal medicine with *undercapacity* between 17h30 and 0h00 on weekdays. - cardiology with *undercapacity* between 10h00 and 20h00 on weekdays. - general surgery with *undercapacity* between 17h00 and 0h00 on weekdays and between 12h00 and 14h00, 16h30 and 21h00 and 23h00 and 01h00 during the weekends
DF_{22}	The 'back-up' resident of the cardiology is called too late and not always available.
DF_{25}	The 'back-up' resident of the general surgery is not always available and often the *youngest* resident is send to the ED. This resident is commonly inexperienced and needs of a lot of supervision and consultations, with the result that throughput does not increase.
DF_{26}	We found indications that the nursing capacity is short during lunch and supper breaks.

Table 2.16: Overview of delaying factors not quantified.

We state that the main focus areas for improvement are the availability of doctors (see $DF_{6,\ 11,\ 20\text{-}25}$) and the waiting time before laboratory test results are available (see DF_{15}). Both DFs cause relative long waiting times and many patients are affected by these delays.

However, due to the high level of variability in the entire throughput process, we conclude the best results can be obtained by not only focusing on identifying interventions to reduce large delays, but for as many delays as possible. A small delay in the beginning of the throughput process, can cause long delays later on in the process. In the next chapters the findings of this chapter are used to identify and suggest possible interventions to decrease the patient LOS by reducing delays.

Chapter 3 Literature

In this chapter, we describe relevant literature that can be used to identify interventions and to reduce the delays identified in Chapter 2. We start this chapter with clarifying the most important conclusion from our literature review in Section 3.1, namely that we need a customized approach to determine interventions. In Section 3.2, we continue describing a threesome manufacturing theories that provide useful insights, and in Section 3.3, we describe a control and planning framework we use to demarcate our scope towards identifying interventions.

3.1 Need for customization

Numerous reports are written on identifying and eliminating delays in ED throughput flows, with most commonly the purpose to reduce the moments of overcrowding from happening. However, despite all investigations executed and reports written, there is no strategy or guidance available to identify interventions which guarantee to be effective (Paul, Reddy, DeFlitch, 2010; Oredsson et al., 2011; Morris et al., 2011). Although there is an established literature upon the *consequences* of overcrowding, the only consensus found in literature upon the *causes* and *solutions* is that these are ED dependant. Causes of delays differ between EDs, and even when the main cause of delay is the same at two EDs, contextual factors may result in a successful intervention at one ED failing at the other. Therefore, literature only provides suggestions what *could* be done to improve patient flows, not what *should* be done. Concluding, we need to conduct a design study, in which we use a customized approach to determine interventions for the delaying factors we identified.

3.2 Insights from manufacturing theories

Different manufacturing theories provide valuable insights, which we can apply to analyze and improve the performance of the ED. We use insights obtained from *factory physics*, *lean manufacturing* and *capacity management*.

Factory physics

One of the fundamental relations within manufacturing is the relation known as Little's Law. Little's Law state that the average cycle time of a system over a longer period of time depends on the average number of products in the system (Work-In-Progress) and the average throughput time of finished products within a period of time, see equation 3.1.

(equation 3.1) Work in Progress (WIP) = Cycle time (CT) * Throughput (TH)

This law implies that for a fixed TH, the WIP can be reduced by reducing the CT. High WIP levels are commonly caused by large queues in a system (Hopp and Spearman, 2000), and therefore when the length of the queues (CT_q) are reduced, CT decreases and the WIP levels decrease. This relation is captured in equation 3.2.

(equation 3.2) Cycle time (CT) = waiting time in queues (CT_q) + effective processing time (t_e)

But how can we reduce the waiting time of the queues? What factors influence the length of queues? The answer is given by the *VUT- equation*, as shown in equation 3.3. This equation shows that the time a product waits in queues for a station (CT_q) depends on the coefficient of variation of the stations arrival process (c_a^2), the coefficient of variation of the stations processing times (c_e^2), the stations utilization (u), and effective processing time of the station (t_e).

(equation 3.3) $$\mathrm{CT_q} = \left(\frac{C_a^2+C_e^2}{2}\right)\left(\frac{u}{1-u}\right)t_e$$

Therefore, $\mathrm{CT_q}$ can be reduced by either decreasing the variability in the arrival process or in the effective processing time of the station, or by processing more products within the same period of time by increasing the stations utilization or decreasing the effective processing time of one product.

Another important insight provided by Hopp and Spearman (2000) is that the throughput of a system with serial linked activities is as high as the throughput of the slowest station, referred to as *the bottleneck*. By improving the throughput of the bottleneck, the overall systems performance increases.

Lean manufacturing

Lean manufacturing is a philosophy developed in 1980s by the Japanese car manufacturer Toyota to obtain a competitive advantage over other established car manufactures in America and Europe. The philosophy is concerned with compressing the time period between order and delivery, by identifying and eliminating sources of *waste* ('muda'). All activities that do not add value to the final product from a customer's point of view are *waste*, and should be eliminated.

Although the emergency department differs in many ways from an industrial car manufacturing company, the basic principles have shown to be applicable in health care systems as well (Rosmulder, 2011; Walley. 2003). The ED's products are the ED's patients, and each step in the throughput process of patients that does not add value should be eliminated. Within the lean philosophy there are seven sources of waste distinguished (LeanManufacturingTools.org, 2011):

(1) **overproduction**; e.g. inexperienced doctors requesting more diagnostics test than necessary (known as 'over diagnostics' of patients).
(2) **transportation of products***;* e.g. relocating patients to and from hallway beds.
(3) **unnecessary processing**; e.g. taking blood samples of patients while not used.
(4) **inventory**; e.g. large amounts of materials and drugs kept available, while always only small amounts are used.
(5) **unnecessary motion of personnel**; e.g. nurses and doctors searching each other.
(6) **defects**; for clarification, defective products might impede flows and lead to rework that costs time and money. An example of rework on the ED are residents who 'repeat' activities already executed earlier by co-assistants, as well as patients who need to tell their story several times to different nurses and doctors.
(7) **waiting***;* e.g. waiting for a doctor, a CT-scan or a ward nurse when admitted.

Capacity management

The basic idea of capacity management is that capacity and demand should be in balance and capacity decisions need to be made upon the availability of staff, equipment and facilities. When capacity exceeds demand, capacity remains unused. In this way, money is wasted as costs are made, without having a return. On the other hand, when demand exceeds capacity, the output is not as high as it could be and *sales* are missed (Reid and Sanders, 2005), or, in terms of acute care delivery, unsafe situations can occur (Hoot, 2008; Wiler, 2010).

Capacity management on EDs is difficult, due to several sources of variation in the arrival process and activity durations of different patients. According to Hopp and Spearman (2000) variability can be captured by buffering with: (1) inventory, (2) time, and/or (3) capacity. Of these buffers, inventory is not an option at the ED. Immediate care cannot be produced in advance and stored to be used during moments of crowding (Elfring en Aa, 2003). The other two buffers are possible. Variability can be dealt with by letting patients wait, as well by having overcapacity.

3.3 Planning & Control Framework

Hans et al. (2011) provide a hierarchal framework that can be used as a tool to structure and break down all functions of health care planning and control. The main advantages of this generic framework is that it includes *medical planning* as a separate managerial area and is practical to use. In Figure 3.1, we provide an overview of the framework.

	Medical planning	Resource capacity planning	Materials planning	Financial planning
Strategic	Research, development of medical protocols	Case mix planning, capacity dimensioning, workforce planning	Supply chain and warehouse design	Investment plans, contracting with insurance companies
Tactical	Treatment and protocol selection	Block planning, staffing, admission planning	Supplier selection, tendering	Budget and cost allocation
Offline operational	Diagnosis and planning of an individual treatment	Appointment and workforce scheduling	Materials purchasing, determining order sizes	DRG billing, cash flow analysis
Online operational	Triage, diagnosis emergencies and complications	Monitoring, emergency coordination	Rush ordering, inventory replenishing	Billing complications and changes

Hierarchical decomposition

Managerial areas

Figure 3.1: Framework for health care planning and control, applied with an example (Hans et al., 2011).

Hans et al. (2011) distinguish four managerial areas. The *medical planning* area concerns planning and decision making by healthcare professionals, e.g. upon treatment methods, usage of protocols and activities performed during anamnesis. *Resource capacity planning* concerns planning, scheduling and controlling of renewable resources, like staff, rooms, and equipment (e.g. X-ray and ECG devices, and CT-scans), while *material planning* concerns acquisition, storage and distribution and retrieval of consumable resources (e.g. blood, plaster and bandages). The last area concerns the financial planning, in which financial decisions need to be made upon costs and revenue of an organization. Contrary to the medical planning area, in the other three areas the decisions can be made both by healthcare professionals and managers working in the care institutions.

The different managerial areas are also decomposed by four hierarchical levels of decision making. The strategic level concerns structural decision making with a long planning horizon, e.g. should at least one ED physician be available 24/7, and if so, do we need to hire additional ED physicians? The tactical level concerns the translation of strategic choices in medium-term objectives. Using our example, a decision on tactical level would be: should we temporarily expand (e.g. caused by prolonged disease or pregnancy) the capacity of ED physicians to guarantee the 24/7 availability? Towards the operational level, Hans et al. (2011) distinguish between *offline* planning and *online* planning. The offline operational planning deals with the in advance planning of day-to-day operations, e.g. rostering the ED physicians. However, as many aspects cannot be planned in advance due to the stochastic nature of health care processes, *online* reactive decision making is needed. These decisions are made on the moment itself, e.g. an ED physician deciding to temporarily stop a patients treatment due to a large trauma coming in.

In this research, we demarcate our scope towards identifying interventions to the first two managerial areas: *medical planning* and *resource capacity planning*. We have no indications that the delays on the ED are caused by consumable resources not being available (Observations, 2011), and the financial performance of the ED is beyond the scope of this research.

Chapter 4 Interventions

In this chapter, we suggest interventions to reduce the DFs identified in Chapter 2. Using literature we initially identify sixteen promising interventions. In Table 4.1 we provide an overview of these sixteen interventions, how they are related to the DFs, and whether we need extensive additional research to assess them.

Suggested intervention	DFs	Ref.
Not in need of extensive additional research		
➢ Modify the working schedule of the internal medicine residents	$DF_{6,11,20}$	4.1.1
➢ Schedule an extra resident cardiology	$DF_{6,11,21,22}$	4.1.2
➢ Resident should join co-assistant during first patient visit	$DF_{4,13}$	4.2.1
➢ Place patients in treatment rooms grouped towards specialty	DF_{11}	4.2.2
➢ Doctors should start a patients treatment also when they are near the end of their shift	DF_{7}	4.2.3
➢ Send patients to the AADU earlier	$D_{4,11,13}$	4.2.4
➢ Enlarge initiative of X-ray technicians	DF_{16}	4.2.5
➢ Actively notify doctors that test results are available	DF_{14}	4.3.1
➢ Inform patients more actively by frequent short visits	DF_{12}	4.4.1
➢ EPRs not in use should automatically change to status ‘read only’	-	4.3.2
Extensive additional research needed		
➢ Starting blood tests by triage nurse	$DF_{2,3,15}$	Chapter 5
➢ Investigate the accessibility of the cardiology outpatient clinic	DF_{1}	6.3.1
➢ Improve the accessibility of supervisors	DF_{5}	6.3.2
➢ Reduce waiting times for external actors	$DF_{8,9,10}$	6.3.3
➢ Digitize requests of X-rays, CT-scans and ultra sonograms	$DF_{17,18,19}$	6.3.4
➢ Digitize the process of finding an inpatient bed	-	6.3.5
No intervention	$DF_{23,24,25,26}$	4.1

Table 4.1: Relation between suggested interventions, DFs and recommendations for additional research.

We investigate the suggested interventions *not in need of extensive additional research* in this chapter. However, as we are limited by time, we are unable to also investigate the other six suggested interventions. In consultation with an ED physician and the manager of the RVE acute care we decide that ‘starting blood tests by the triage nurse’ is the most promising intervention, as we perceive significant benefits in terms of patient LOS reduction, no external actors have be involved to realize this intervention, and no costs have to be made. We hypothesis that the patient LOS of a specific group of non-ambulance patients can be decreased by starting their laboratory blood test already during the triage, instead once the patient is placed inside a treatment room and the nurse anamnesis is conducted (see Figure 2.3). We investigate this intervention in detail in Chapter 5.

Of the ten interventions investigated in this chapter, two are *staffing capacity* related (see Section 4.1), five *process* related (see Section 4.2), two *ICT* related (see Section 4.3), and one intervention concerns *providing information* towards patients (see Section 4.4). We investigate each of the intervention individually, and assess them on *costs*, *feasibility* (‘the degree with which changes have to be made towards the EDs lay-out, the ICT systems used, and in the way staff works’), and *intervention specific* pros and cons. We end the chapter with a summary (see Section 4.5).

4.1 Staffing capacity interventions

In literature, a commonly mentioned possibility for improvement is establishing a better match between staff availability and demand (Green, 2007; Morris et al., 2011). Capacity management states that capacity and demand should be balanced to prevent waiting by either staff or patients, and the lean philosophy states that waiting is a *waste* that should be eliminated. Paul, Reddy, and DeFlitch (2010) even conclude that the likelihood of reducing waiting times on EDs is the highest by more effective scheduling of doctors.

In our contextual analysis, we identified indications for a mismatch in doctor capacity of the *internal medicine* (DF_{20}), *cardiology* (DF_{21}) and *general surgery* ($DF_{23,24}$), as well as delays caused by insufficient nursing capacity available during breaks (DF_{26}). For the *internal medicine* and *cardiology* we identify opportunities to match capacity and demand better, which we describe in Subsection 4.1.1 and 4.1.2 respectively.

Towards the doctor capacity available of the general surgery, currently no measures should be taken. In May 2012 the ED becomes part of the integrated emergency post, with the result that a forecasted 54% of the patients who are currently seen by doctors of the general surgery bend away towards the GP post (see Section 2.6). At that time it is very likely that the current *undercapacity* changes towards *overcapacity,* however, as the exact consequences at this moment are too unsure[4] we suggest to keep the situation unchanged for now.

The nursing capacity is not in need of change either. Although we found some indications of delays caused by insufficient nursing capacity during lunch or supper breaks, they are relatively small and are not of significant importance to further focus upon.

4.1.1 Intervention A: Modify the working schedule of the resident's working for the internal medicine

We have strong indications that the capacity of the residents working for the internal medicine can be allocated more efficiently during weekdays. With two residents working each dayshift and one resident working in the evening shift, we identified in Figure 2.22 *overcapacity* between 09h15 and 13h30, while *undercapacity* between 17h30 and 0h00 (see DF_{20}). This finding is also supported by the residents of the internal medicine, who indicate that they experience high levels of workload in the beginning of their evening shifts (Interviews, 2011), as well as we observed that the residents in the morning often are waiting for patients to arrive, but also stay longer in the begin of the evening to help their colleague working the night shift.

To overcome these capacity inefficiencies, we suggest to change the working shifts of the resident´s of the internal medicine. Instead of two residents starting in the day shift of 08h30, only one resident works the day shift from 08h30 to 17h00, while the second should works a *new* shift from 12h00 to 20h30, see Figure 4.1. In this way, the capacity that remained unused during the morning is efficiently allocated during the beginning of the evening.

[4] *Partly because the negotiations with the GPs are still continuing.*

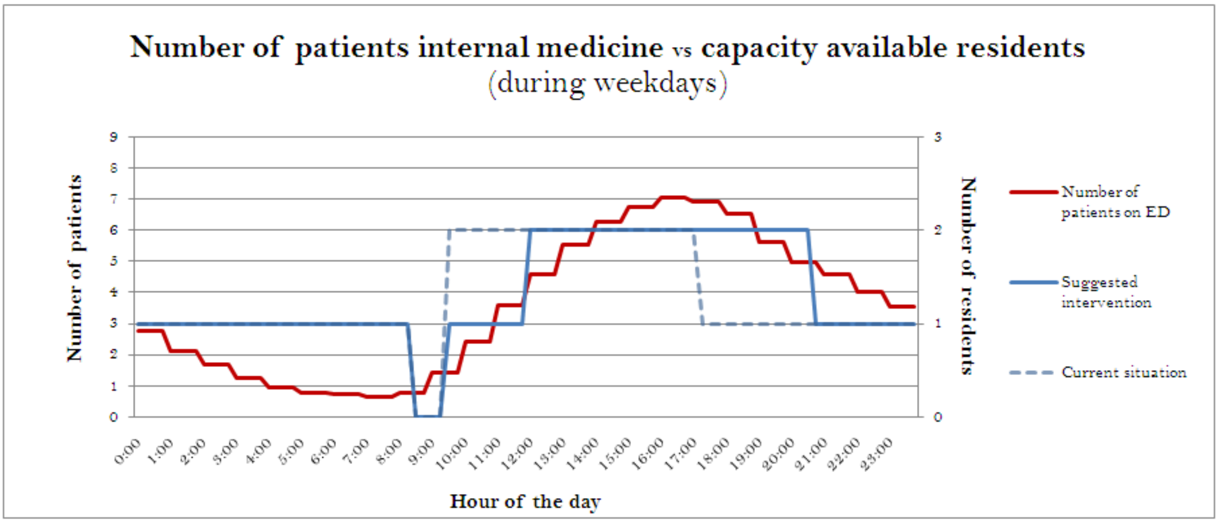

Figure 4.1: Introducing a new working shift for the internal medicine (Intervention A).

Assessment

The main advantage of allocating the doctor capacity more efficiently is that the performance can be improved without making additional costs. Delays in the throughput process of patients for the *internal medicine* during the evening are directly reduced (see also $DF_{6,11}$), more patients will have their initial doctor contact within the norm set by triage, as well as we perceive that also other patients and staff members indirectly benefit from the ED being less crowded.

A disadvantage of this intervention is that the residents working in the *new* shift miss the morning meetings and therefore possibly miss education moments. However, two residents of the internal medicine spoken about this intervention indicate that advantage of an additional resident during the evening outweighs this disadvantage. Additionally, not every meeting contains educational moments (Conversation with residents, 2011), and when residents rotate between shifts the number of missed educational moments can be minimized.

Concluding, this intervention provides a great opportunity for improvement, and as this intervention can be easily be realized without additional costs, we recommend to adopt this intervention.

4.1.2 Intervention B: Schedule an extra resident cardiology

Our contextual analysis provides strong indications that the capacity of the cardiology is insufficient during weekdays. The cardiology scores worst on their 'initial time to doctor contact' (see Table 2.7). Our *capacity vs demand* analysis reveals that the number of residents is insufficient during 10h00 and 20h00 on weekdays (see DF_{22}), and three ED physicians and five nurses are unanimous in their believe that the cardiology is in general the specialty most often struggling with capacity shortages (Interviews, 2011).

We suggest that an additional resident of the cardiology should be scheduled in a new shift from 10h00 and 18h30, as shown in Figure 4.2.

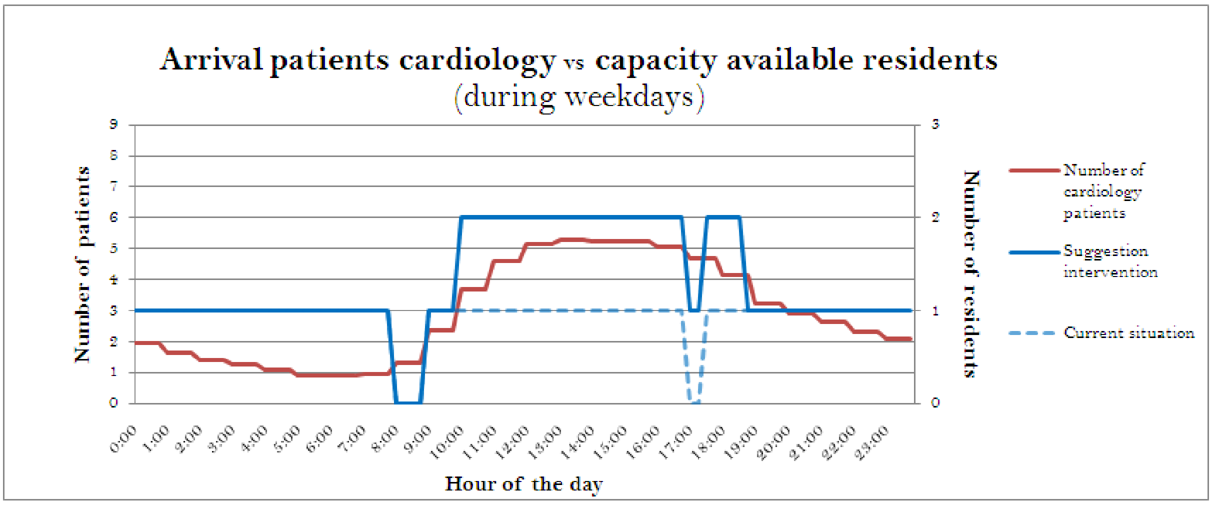

Figure 4.2: Introducing a new working shift for the cardiology (Intervention B).

Assessment

The main advantage of having two residents available during the most crowded hours is that the waiting times of the cardiology patients decrease (see also $DF_{6,11}$), more patients can have their initial doctor contact within the norm set by triage, and delays caused by doctors not starting patient treatments at the end of their shift (see DF_7) likely reduces as the two residents can practically divide who treats which patients.

We also perceive a strong effect of decreasing frustration levels of staff and the ED being less crowded, resulting in less frequent use of hallway beds (see DF_{13}). Other advantages are that the 'back-up' resident is not needed anymore (see DF_{22}), more time becomes available for teaching moments with co-assistants, as well as we believe that the chances of mistakes are reduced by reducing the workload of the solely resident.

But these advantages have to be weighed against the disadvantage of extra costs that have to be made, without an increase in revenue. An additional resident for the cardiology has to be hired, costing an estimated €35.000 extra a year, and it is likely that his/her capacity is not fully used (see Figure 4.2).

Concluding, as we believe that the pros outweigh the cons, we recommend to adopt this intervention. In this decision we include that we believe that especially the *cardiology* is the specialty of whom it is the least desirable having *undercapacity*. The acute care is one of the profile areas of HagaZiekenhuis, in which the emergency cardiac center has an important function to accelerate upon. When HagaZiekenhuis wants to profile themselves in a rising competitive health care market, fast access to care in their emergency cardiac care centre and treatments without long delays yields a competitive advantage.

4.2 Process interventions

We identify five possibilities for improvement related to the working processes on the ED. According to the fifth and sixth *muda* of lean manufacturing, rework and unnecessary motion of staff should be prevented. Applying these principles on the ED, we suggest that time can be saved when the resident joins the co-assistant directly during their first patient visits (see Subsection 4.2.1), and travel time can be saved when patients for the same specialty are placed in rooms near each other (see Subsection 4.2.2). Our third process intervention focuses on reducing waiting times caused by doctors not starting a patient´s treatment at the end of their working shift (see DF_7; see Subsection 4.2.3). Fourth, we suggest to use the services of the acute admission and diagnostic unit more (see Subsection 4.2.4), and last, we suggest to start the conversation with the X-ray technicians to increase their initiative (see Subsection 4.2.5).

4.2.1 Intervention C: Resident should join co-assistant during first patient visit

The residents of the largest four specialties working at the ED often have a co-assistant joining them. The expertise and assertiveness of the co-assistants fluctuates, resulting in that the 'benefit' of having the co-assistant fluctuates as well. We observed that some co-assistants have a role in which they observe the resident working and answer questions residents ask them (teaching moments), while other co-assistants are send to the patient preceding the resident. In this situation, the co-assistant conducts an anamnesis, sets a diagnosis, and write his/her findings down in the patient's medical record (EPR). Once completed, the findings are discussed with the resident and together they visit the patient again. The resident commonly performs the anamnesis themselves again, verifies the work of the co-assistant and sets the actual diagnosis and/or treatment plan.

Although we understand the importance of the educational purposes of teaching co-assistants, a drawback is that the patient LOS increase. The time it takes for the co-assistant to conduct their anamnesis, work out their findings and discuss those with the resident are non value adding activities from a patient perspective. Even when the co-assistant and resident work parallel on different patients, the patient LOS of the patient first seen by the co-assistant still increases. Instead of the resident continuing directly with the patient seen by the co-assistant, the findings of the co-assistant are first discussed.

To minimize the delays caused by co-assistants preceding residents, we suggest that residents should join their co-assistant during the first patient visit. The co-assistant should still conduct his/her anamnesis and write his/her findings in the EPR, but the advantage is that the resident can immediately provide possible useful instructions and start diagnostic tests if necessary.

Assessment

We recommend to adopt this intervention, in order to reduce the patient LOS of patients who are initially seen by a co-assistant. There are no costs attached and the intervention can easily be realized.

4.2.2 Intervention D: Place patients in treatment rooms grouped towards specialty

To work more structured and to prevent staff from wasting time by movement, we suggest that patients of the same specialty should be placed as much as possible in rooms closely to one another. To clarify, currently there is no control mechanism to regulate in which room a patient needs to be placed on the medium/high care. Ambulance nurses arriving with new patients are often told to 'pick one of the empty lodges' (Observations, 2011) and there are no rules upon placement of patients from the waiting room.

We observed that time is wasted by unnecessary movement of staff. To explain; when for example a doctor has one patient in one of the hall treatment rooms (see Figure 2.12), one patient in bed 2 and one patient in bed 10 of the cardiac emergency care, time is wasted by walking from one patient to another. But also time of nurses is wasted. When the doctor is working *out of sight*, we observed that nurses had to search for the doctor to ask treatment related questions, like 'can I provide the patient with some additional pain killers?', but also to ask whether the doctor had not forgotten his/her patient.

To reduce time wasted with unnecessary movements of staff, we suggest that patients for the same specialty should be placed in rooms closely to one another as much as possible. Based on the locations of the computers commonly used by the internal medicine, neurology and cardiology residents respectively, we suggest to use the three hall treatment rooms (plus *trauma room 2* during crowding moments) for the neurology and general surgery patients, the beds one to four of the emergency cardiac care for the internal medicine and the beds five to ten of the emergency cardiac care for the cardiology. Note, we do <u>not</u> suggest to dedicate these rooms to a specific specialty, only to group patients if possible.

Assessment

This intervention only works when several rooms are available, i.e. during relative calm moments. During these moments, e.g. during the beginning of a day, this intervention can reduce time wasted by unnecessary movements of staff. However, when the ED becomes more crowded patients mix up again. Despite this drawback, placing patients in groups together benefits during the calm moments. Also are there are no costs attached, and can this intervention be realized easily. Concluding, we recommend the ED to adopt this intervention.

4.2.3 <u>Intervention E</u>: Doctors should start a patients treatment also when they are near the end of their shift

We observed that doctors do often not start a patients treatment at the end of their working shift (see DF_7), causing delays for patients. However, in the doctors defense, doctors claim that this is in the best interest of patients for two reasons: (1) transferring patients between doctors should be reduced as much as possible due to increased changes of medical errors caused by missing information, and (2) studies have shown that an important factor of dissatisfaction among patients is telling their story over and over again (Interviews residents, 2011).

Assessment

Although we agree upon the second aspect, we believe that lack of efficient communication and information sharing should not be an accepted reason for the presence of delays. And even though the patient has to tell specific aspects twice, or a physical anamnesis is performed twice, we believe the advantages of time saved by, for example, starting diagnostic tests outweigh these drawbacks. Concluding, we recommend to adopt this intervention.

4.2.4 <u>Intervention F</u>: Send patients to the AADU earlier

To obtain a high ED logistical performance, good cooperation between the ED and other units of the hospital is necessary. We believe the ED can increase her performance by sending patients earlier to the AADU.

The AADU was recently opened in 2011 and is used by the specialities *internal medicine* and *general surgery* to admit patients. The purpose of the AADU is to ease the ED, by serving as a diagnostic centre and holding unit to admit patients. However in practice, patients are not send to the AADU before all tests are done and a complete diagnosis and treatment is set. Even when during an early stage of the patients stay, the resident decides that the patient needs to be admitted, all tests are started on the ED, the patients waits on the ED for the results and a treatment plan is set (Observations, 2011). According to the residents it is impractical to send a patient earlier to the AADU, because then the patient needs to be transferred to the resident working at the AADU. This resident does not know the patient and his/her background, and 'needs to start almost all over again' (Interviews, 2011).

To gain time, we suggest that a patient who does not need an X-ray, should be send to the AADU at the moment the doctor decides to admit the patient, given that the AADU has at that moment the capacity to continue the treatment of the patient. As the X-ray pictures are made on the ED it is impractical to admit these patients before the picture is taken, but all other diagnostic tests can also be requested and processed by the resident working on the AADU.

Assessment

The advantage of sending patients in an earlier stage to the AADU is that ED capacity becomes *free* and can be allocated to other patients, as well as resources of the AADU are used more efficient. Although we foresee difficulties realizing this intervention, due to residents not wanting to send away their patient before they complete all activities (Conversations, 2011), we recommend to adopt this intervention. To make this intervention successful, all specialists and residents should be made clear the advantage of sending patients to the AADU during an early stage.

4.2.5 Intervention G: Enlarge initiative of X-ray technicians

Observations revealed that both patient and X-ray technician can be waiting (see DF_{16}) when no nurse or logistical employee is available to bring the patient to the X-ray room. Currently, the ED staff is responsible for bringing the patients to the X-ray room, while the X-ray technicians are responsible for bringing the patients back afterwards. Therefore, it depends on the initiative of the technicians whether they actually wait until a patient is brought, or whether they get the patient themselves if the X-ray is idle. Although we would like to change the control mechanism by making both ED staff and X-ray technicians responsible, doing so could induce that nobody feels actual responsible anymore. Therefore, we suggest to start the conversations with the X-ray technicians to raise awareness and increase their initiative.

Assessment

We recommend to adopt this intervention. With this simple intervention that has no costs and is easy to realize, the LOS of some patients can be decreased.

4.3 Information and communication technologies

ICT possibilities are commonly poorly exploited in health care institutions (Reid et al. 2005), and also we identified two non value adding activities that staff needs to execute due to lack of ICT support. These two activities provide ICT related possibilities for improvement, which we describe separately in this subsection.

4.3.1 Intervention H: Actively notify doctors that test results are available

Currently, there is no audio or visual sign available that actively notifies doctors that test results are available. Doctors must open the EPRs of their patients once-in-a-while to determine whether the test results are already available, with the result that each time the tests results are not yet available, time of the doctor is *wasted* (see DF_{14}).

The lack of an active sign also causes delays for patients, when test results remain longer unused than necessary. To clarify, when a doctor determines that the test results are not available yet, (s)he continues with the treatment of another patient. And although the test results can become available 10 seconds later, it commonly takes a while before the doctor checks the EPR again. Therefore, we suggest that doctors should be warned when test results are available.

But considering the type of signal, we suggest to use a visual signal and not an auditory. Many medical devices already use auditory alarms, and in combination with the many telephones and pagers continuously going off, an additional 'noise' should be prevented. We advice to use screens located on strategic places on the ED, showing an overview of patients present on the ED, with status updates towards whether diagnostic test results are available (i.e. laboratory test, CT-scans, ultra sonograms and X-ray pictures).

Assessment

The advantages of this intervention are clear. Waiting times of patients reduce and the productivity of staff increases by wasting less time checking the availability of test results. On the other hand, the disadvantage is that costs have to be made to develop the system. Software needs to be written that subtracts the desired data from the EPRs and projects them in a predefined format on the screens. However, as the data is already available and a relatively simple piece of software is needed, we presume that the development costs can never be high when executed internally. Concluding, we recommend to adopt this intervention.

4.3.2 Intervention I: EPRs not in use should automatically change to status 'read only'

Time of doctors and nurses is wasted by an imperfection in the ICT software of SAP. When a patient record is opened on one computer, the EPR can only be opened on another computer in a 'read only' status. Although this feature prevents the occurrence of two versions, problems arise when an EPR is not closed after being worked with. The status of the EPR is not automatically changed, with the consequence that once-in-a-while a nurse or doctor has to check all computers on the ED to find where the EPR is left open. To prevent this in the future, we suggest that a software change needs to be executed that changes EPR statuses towards 'read only' when no modifications are made in the record during one minute.

Assessment

We recommend to adopt this intervention. With a small software modification, time of staff can be saved. But the most important is that frustrations caused by this imperfection are eliminated.

4.4 Inform patients

According to literature, it is important to inform patients during all stages of their stay. Thompson (1996) concludes that informed patients are more satisfied, and mentions that lack of information magnifies patients' sense of uncertainty and increases their psychological distress. Campbell et al. (2004) addresses this importance of informing patients as well, by suggesting that *communication with patients* should be included as one of the strategies to manage an ED.

Also we observed that patients become restless if they have to wait, often resulting in staff being 'disturbed'. To prevent this from happening, we suggest that nurses and doctors should inform patients more actively.

4.4.1 Intervention J: Inform patients more actively by frequent short visits

Staff members are 'disturbed' with questions (see DF_{12}), when patients become restless (Observations, 2011). Although both nurses and doctors inform patients at the moment they leave upon possible waiting times, there is an opportunity for improvement in providing more updates. For example, doctors should not wait 60 minutes to return back to the patient with the laboratory test results, but quickly walk in 1 or 2 times for a few seconds and provide a short update. Although the content of the update likely provides less value ('we are waiting'), the patient knows that (s)he is not forgotten, which reassures the patient and likely reduces the change of colleagues being 'disturbed'. Although we used the doctors as an example, we believe the biggest role is reserved for the nurses. The nurses are assigned to a specific area of the ED, which makes it easy for them to quickly walk in now and then and provide a short update or answering questions.

We believe that the best results are obtained when this intervention is combined with *intervention D*. When both doctor and nurses work together in a specific area, informing each other and informing patients upon progress becomes far more easy.

Assessment

We recommend to adopt this intervention. There are no costs attached to this intervention and it easily can be adopted.

4.5 Summary

In this chapter, we described and assessed ten *suggested interventions*. In Table 4.2, we provide an overview of this chapter´s conclusions.

Inter-vention	Sub-section	Conclusion
A	4.1.1	Modifying the work shifts of residents of the internal medicine during weekdays provide a great opportunity for improvement. Instead of two residents working the day shift from 08h30 to 17h00, only one resident works the day shift, while the second resident should work a *new* shift from 12h00 to 20h30.
B	4.1.2	Scheduling an additional resident for the cardiology in a new shift from 10h00 to 18h30 during weekdays provides an opportunity to decrease the patient LOS at the ED.
C	4.2.1	We recommend that residents start joining their co-assistant during the first time the co-assistant visits a new patient.
D	4.2.2	We recommend that patients of the same specialty should be placed as much as possible in rooms close to one another.
E	4.2.3	We recommend that even when doctors are near the end of their shift, they should start the treatment of a new arriving patient.
F	4.2.4	We recommend that patients should be send to the AADU earlier in the process. When the AADU has the capacity to continue a patients treatment, patients should be send to the AADU at the moment the doctor decides to admit the patient. Except patients of whom an X-ray is needed, because these have to be made on the ED.
G	4.2.5	We recommend to start conversations with X-ray technicians to encourage them to transport patients to the X-ray room themselves when the X-ray room is idle.
H	4.3.1	We recommend to provide doctors easy access to information on whether test results are available, by using screens on strategic places around the ED showing an overview of patients present on the ED, with status updates towards whether diagnostic test results are available.
I	4.3.2	We recommend to modify the underlying software of the EPRs in such a way that unused EPRs are automatically changed to status “read only”.
J	4.4.1	We recommend that both nurses and doctors inform patients more frequently by short visits.

Table 4.2: Summary of Chapter 4.

Chapter 5 Testing the intervention of *the triage nurse starting blood tests* using a simulation study

In this chapter, we investigate our suggested intervention *starting blood tests by the triage nurse.* We perceive that this intervention has great potential in terms of *decreasing patients LOS* and *feasibility*, but additional research is needed to test this perception. We test our hypothesis that the patient LOS of a specific group of non-ambulance patients can be reduced by starting their laboratory blood tests in the triage room, as well as we investigate the additional effects of this intervention.

5.1 Project specification

In this first section, we introduce the believed benefit of starting blood tests by the triage nurse (see Subsection 5.1.1), define concrete research questions (see Subsection 5.1.2), and describe the method used to actually test this intervention (see Subsection 5.1.3). In the remaining sections, we describe the model (see Section 5.2), provide the model results (see Section 5.3), describe and test two additional scenario's (see Section 5.4), and conclude our analysis by answering our research questions (see Section 5.5).

5.1.1 Introduction

In the current situation, laboratory blood tests of non-ambulance arriving patients are started at the end of the nurse anamnesis once a patient is placed inside a treatment room (T5; see Figure 5.1), and the patient waits inside the treatment room (during a period of W3) for the test results to become available (T6). Before the nurse anamnesis, the patient is registered (the end of the registration is represented by T1), waits for triage (W1), is triaged in the triage room (S1), and waits to be placed inside a treatment room (W2). After this, the nurse anamnesis is performed (started at T4) in which blood samples are taken and the blood test is requested (together represented by S2). Finally, once the test results are available at T6, the doctor continues the patient treatment (represented by a period of S3), to the moment the treatment is completed and the patients departs (T7).

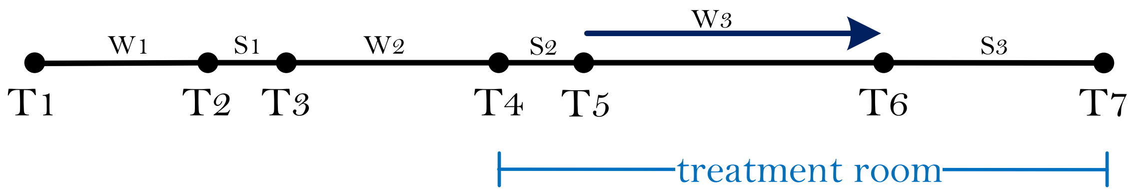

Figure 5.1: Current situation.

We believe the patient LOS can be reduced by starting the laboratory blood tests already during triage in the triage room (at T3; see Figure 5.2). By placing W2 and W3 in parallel, the test results become available earlier in the process, and, under the assumption that S3 remains the same, the treatment of patients will finish earlier in time (Y3). Further, as the time these patients occupy a treatment room is also shorter, we expect that the patient LOS of other patients and/or the number of patients treated in hallway beds decreases as well by an improved access to treatment rooms (W2 declines; later on referred to as *indirect effect*).

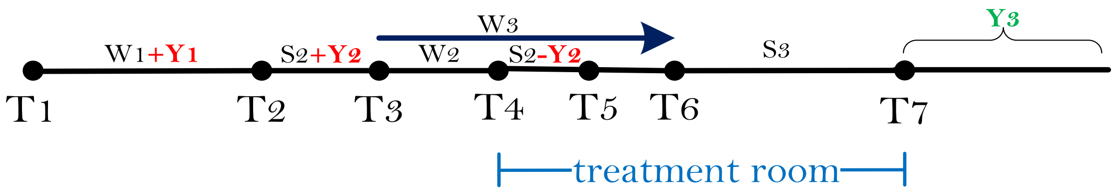

Figure 5.2: Situation with intervention, starting blood tests at triage.

However, a drawback is that the waiting time before the triage room is likely to increase (Y1), as the service time of triage increases when blood samples are taken during triage (Y2; see Figure 5.2).

Concluding, we expect that the patient LOS declines when blood tests are started by the triage nurse. We need a quantitative analysis to test this expectation, as well as to determine the negative influence it has on the time patients need to wait to be triaged.

5.1.2 Objective/ Research questions

To test our expectation, we need to answer two questions: “What is the decrease of patients LOS, when the triage nurse starts blood tests?” (SQ1), and “What is the increase of the waiting time to triage (Y1; see Figure 5.2) when the triage nurse starts blood tests?” (SQ2). Once we obtained the answers to these questions, it is up to the management of the RVE acute care to decide whether the improved patient LOS outweighs the deteriorated access to triage.

5.1.3 Approach

We use discrete event simulation to answer SQ1 and SQ2. Simulation is a commonly used system analysis tool to analyze complex systems, with the great advantage of flexibility in testing scenarios and investigating system’s operational behavior (Paul, Reddy, DeFlitch, 2010; Sinreich and Marmor, 2005) without disrupting the daily ED working processes or putting (additional) pressure on the ED staff by testing interventions in reality.

To structure our simulation we use the 10 steps of Law (2007) as guide, see Figure 5.3. We already formulated the problem and goals of the study in Subsection 5.1.1 and 5.1.2 (*step 1*). In the Subsections 5.2.1 to 5.2.6, we define and build the model (*steps 2 to 5*), and we validate our model in Subsection 5.2.7 (*step 6*). We continue with designing our experiments in Subsection 5.2.8 (*step 7*), and present and analyze the results of the different scenarios in Section 5.3 and 5.4 (*steps 8 and 9*). The simulation is completed in Section 5.5, in which we come to a conclusion on whether we recommend this intervention or not (*step 10*).

We use the software program *Technomatrix Plant Simulation 8.2* of Siemens to construct our model, and we use the data of our measurement (Measurements, 2011) to determine the patient arrival rate and distribution functions of activity durations.

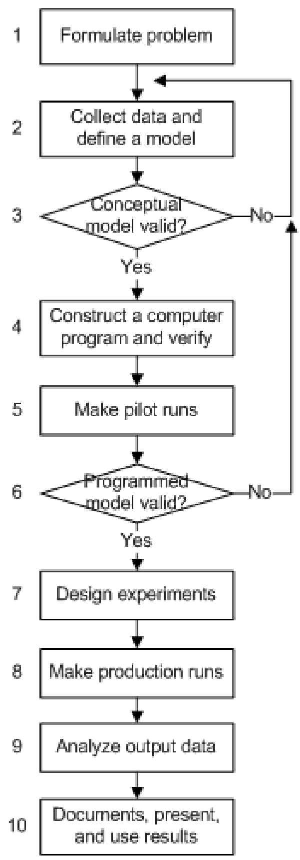

Figure 5.3: Simulation steps (Law, 2007).

The group of patients of whom the blood tests can be started during triage, are the patients who arrive as non-ambulance arrivals and are triaged in the triage room (from now on we refer to this group as *group D10*). From Subsection 2.5.2, we known that 77.1% of all blood requests are requested on the initiative of a nurse. Therefore, to test our intervention, we start the blood tests of 77.1% of the patients in group D10.

5.2 Simulation model

In this section we describe our model assumptions, performance measures, and the simulation model itself in detail. In Figure 5.4 we provide a screenshot of our model.

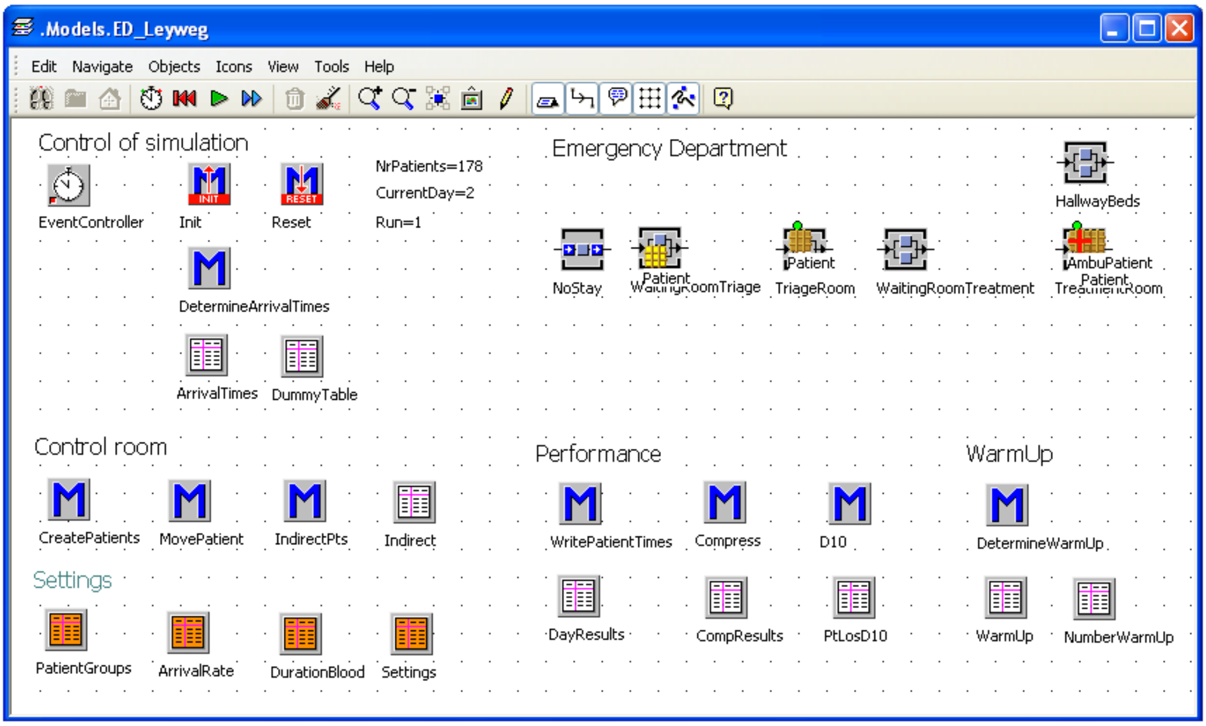

Figure 5.4: Screenshot of simulation model.

5.2.1 Model assumptions

We use the following three assumptions in our model:

1. All patients arriving at the ED are treated. Neither patients leave without being seen, nor do patients leave before their treatment is completed.
2. The time a doctor needs to complete a patients treatment once the blood test results are available (see S3 in Figure 5.2) does not change when the triage nurse starts the blood tests. Therefore, when the triage nurse starts the blood tests, the service time of patients inside a treatment room declines with the same length of time blood test results are available earlier.
3. Patients who are assigned to be treated on the low care or in trauma room 1 are never placed on the medium/high care area for a treatment.

5.2.2 Performance measures

We use three performance measures to determine the effect of our intervention. The measures are:

(1) Waiting time to triage by the triage nurse

The average waiting time to triage is one of the performance indicators of the ED. We use our definition of Chapter 2 stating that the 'waiting time to triage' is *the time between registration and start of triage*. According to the norm (Prins, 2011; NVSHV, 2008), the triage of patients should start within 10 minutes after arrival.

(2) Patient length of stay

The second measure is the patient LOS, which we aim to reduce with our intervention (see SQ1). We define the 'patient LOS' as *the time between registration* (non-ambulance arrivals) *or moment of arrival at the ED* (ambulance arrivals), *and the moment the patient leaves the ED*.

To specify, we focus on the change in patient LOS of the patients of whom their blood test is started by the triage nurse (*direct effect*). Later on, in Subsection 5.2.4, we classify all patients in groups, and this group of patients is a subgroup of class D10. From now on we refer to the group of patients of whom their blood tests is started by the triage nurse as D10-A. The other patients in group D10 are referred to as D10-B, and we use the patient LOS of this group as one of the two measures to quantify the *indirect effect*.

(3) Number of patients treated in hallway beds

The second measure we use to quantify the *indirect effect*, is the number of patients treated in a hallway bed. When the triage nurse starts blood tests, we believe rooms become available earlier due to patients having shorter patients LOS, and this likely results in fewer hallway beds needed.

5.2.3 Level of model detail

Law (2007) states that it is important to find a right balance between *the level of detail included* and *the additional value of including more detail* when a simulation model is build. When more details are included, the amount of work to collect reliable data, build the model, and analyze the results is much more. In addition, model inaccuracy and errors are more likely to occur, and the run time of the model increases, while it does not necessarily lead to a higher accuracy of output.

Considering the questions we want to answer with our simulation, we can answer our second question with a relative simple simulation model consisting of a *triage* station and a buffer in front. The variables in this model are the arrival rate of patients, the service time of triage when no blood tests are started, and the service time of triage when blood tests are started. During our measurement we obtained the data for all three variables, and by using the performance measure *waiting time to triage* as output parameter we can test the effect of starting blood tests at triage.

However, answering our first research question is much harder. The activities performed on (and for) patients after triage are highly divers, and we lack information and data to describe exactly *which*, *when* and *by whom* activities are performed on patients inside a treatment room. In addition, we lack information and data of the activities performed by staff when they are not with a patient in a room.

Therefore, we conclude aggregation is needed and decide to model the service times patients spend inside a treatment room as one period of time. This means, we use "black-box modeling" towards the activities performed on the patient within the treatment room, and we do not model staff or equipment.

But not all blood tests can be started by the triage nurse. Based on conversations with nurses, and confirmed by an ED physician, we assume that the blood tests requested for patients treated on the low care area (7.5% of the patients treated on the low care area (Measurements, 2011)) are always requested by a doctor, or a nurse after consultation with a doctor. Applying this information on our intervention, we conclude that the triage nurse cannot start blood tests of patients who are going to be treated on the low care area. When we further include that patients treated on the low care and medium/high care are separate patient flows (with their 'own' staff, rooms, and patients not being interchanged between the areas), we assume that the patient LOS of patients treated on the low care area is only influenced by a change in waiting time to triage. This group of patients does not benefit from the possible 'indirect effect' of earlier access to a treatment room. Therefore, modeling the throughput of patients through the treatment rooms on the low care area adds no value.

Finally, neither modeling the patients treated in *trauma room one* adds value, because this room is reserved for acute trauma patients. Therefore, under the assumption that patients who need to be treated in *trauma room one* can always be placed inside the room immediately (so they never need to be treated in another room on the medium/ high care area other than trauma room one), this group of patients is excluded in our model.

5.2.4 Model description

To test our intervention we use a simulation model with one *triage* station, one station with 14[5] parallel independent *medium/high treatment rooms,* one buffer representing the availability of hallway beds, and two waiting rooms (in reality the same room). Based on data of patient arrivals, we do not include a station for registration. The arrival moments of patients registered in the electronic patient records (EPRs) correspond with the moment the desk employee finishes the patient registration. Therefore, the times obtained from SAP (which collects the data from the EPRs) correspond with the times the registration of patients is finished, equaling the moment the patient is asked to take a seat in the waiting room to wait for triage. In Figure 5.5, we provide a schematic overview of the stations in our model.

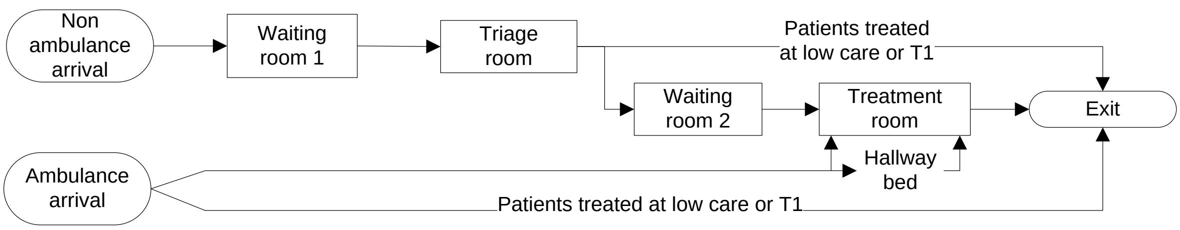

Figure 5.5: Overview of stations modeled.

[5] *Trauma room 2 is included as one of the normal treatment rooms on the medium/high care area (which consist of 13 treatment rooms), as we observed that during moments of crowding this room is used as `regular´ treatment room.*

To simulate the throughput process of patients, we classify all ED patients in groups based on four criteria (‘properties’ of the patients). Each patient group corresponds to a particular set of properties, and each set represents a particular process path. We further distinguish between ‘hours of the day at which the triage room is open’ (between 07h30 and 23h15; see Table 5.1) and ‘hours of the day at which the triage room is not open’ (between 23h15 and 07h30; see Table 5.2). The fractions of each group are based on the data of our measurement.

Group	Way of arrival	Direct, or via triage room	Location treatment	Patient receives blood test?	Perc. patients
D1	Ambulance	Direct	Low care	*Irrelevant*	2.47%
D2			Med/High care	Yes	18.09%
D3				No	1.64%
D4			Trauma 1	*Irrelevant*	1.48%
D5	Non-ambulance	Direct	Low care	*Irrelevant*	2.28%
D6			Med/High care	Yes	1.58%
D7				No	0.18%
D8			Trauma 1	*Irrelevant*	0.35%
D9		Triage room	Low care	*Irrelevant*	41.47% [1]
D10			Med/High care	Yes	26.33% [2]
D11				No	3.96% [3]
D12			Trauma 1	*Irrelevant*	0.17%
Including the patients who are taken to a treatment room before they are triaged in the triage room (indirect flow): [1] 7.52%, [2] 5.07% , and [3] 1.05%.				Sum	100.0%

Table 5.1: Arrival categories of patients between 07h30 and 23h15 (Measurements, 2011; n=616).

Patients arrive at the ED, either brought in by ambulance or as walk-in arrival through the front door, which we refer to as non-ambulance arrivals. Ambulance arrivals are directly placed in a treatment room, or, if all treatment rooms are occupied, in a hallway bed. Their treatment starts immediately (start of the ‘black box’ period) and patients are relocated from hallway beds to a treatment room, when a room becomes available. To simulate the use of hallway beds, we use a control mechanism in our model stating that once a treatment room becomes empty and patients are laying in hallway beds, the patient laying the longest is relocated to the treatment room. Also, patients laying in hallway beds are given priority to non-ambulance arrivals waiting for a room.

Unlike the ambulance arrivals, non-ambulance arrivals are not always directly placed in a bed at arrival. In Chapter 2, (see Figure 2.2) we distinguished three paths non-ambulance arrivals can follow to be placed in a treatment room; *directly, via the triage room,* and *indirectly*. We model the group *directly* as the patients who are directly placed in a treatment room at arrival, or, when all rooms are occupied, in a hallway bed. All other patients are considered as patients following the path: registration (not modeled), waiting in waiting room to triage, triage room, wait again to be placed in a treatment room, and then are placed in a room. However, as shown in Table 5.1, a fraction of these patients are taken out of the waiting room before they are triaged. In Appendix B, we describe in detail how we modeled this group of *indirect* non-ambulance arrivals.

Note that 5.1% of group D10 is taken indirectly, yielding that 21.2% actually go to the triage room. As we also know that 77.1% of the blood tests is requested on the initiative of a nurse, we conclude that the group of patients of whom the triage nurse can starts blood tests during our intervention (D10-A) is 16.3% of all patients.

To control the waiting rooms, we use the priority rule of first come first serve. Including more difficult selection rules is of no use, as we do not distinguish between specialty, urgency, or care need of patients in our model. We also provide each patient with a minimum time they spend in one or both of the waiting rooms. This is necessary to prevent our model to be to 'positive' in terms of throughput times. We observed that patients can be waiting in the waiting room, while the triage room is empty, or, in case the patient needs to be placed in a treatment room, while not all treatment rooms are occupied. These waiting times are caused by unavailability of staff, e.g. the nurses working on the ED area where the patient needs to be treated are all busy with activities for other patients. But as we do not include staff availability in our model, we include minimum waiting times to simulate reality as good as possible. We describe the probability distribution functions used to model these waiting times later on in the paragraph *input distributions*.

We also simulate the arrival and treatment of patients outside the opening hours of the triage room (07h30-23h15) to determine the initial conditions of each run (see Subsection 5.2.8). As during these hours the triage room is not open, these patients are all directly placed inside a treatment room after arrival, or, when all rooms are occupied, inside the waiting room or in a hallway bed, depending on whether the patient is a non-ambulance or ambulance arrival. We provide an overview of the identified patient groups at night in Table 5.2.

Group	Way of arrival	Location treatment	Patient receives blood test?	Perc. patients
1	Ambulance	Trauma 1	*Irrelevant*	1.31%
2		Med/High care	Yes	32.66%
3	Non-ambulance	Low care	*Irrelevant*	25.90%
4		Med/High care	Yes	32.37%
5			No	7.77%
			Sum	100.0%

Table 5.2: Arrival categories of patients between 23h15 and 07h30 (Measurements, 2011; n=108).

Now that we described our way of simulating the ED and her patients, we need to define the input data of our model.

5.2.5 Input distributions

To carry out our simulation, we use probability distributions to simulate the sources of randomness on the ED. In this paragraph, we determine the probability distributions of the *inter-arrival times of patients arriving at the ED*, the *time patients spend at the different stations*, and the *waiting time before laboratory test results become available*. And also in here, we use our measurement results to determine these distributions (Measurements, 2011; n=724).

Arrival process

To simulate the arrival process of patients at the ED we need to generate a sequence of random points in time with $0 = t_1 \leq t_2 \leq$ …, such that the *i*th patient arrives at time t_i (i=1,2,…) and the distribution of the arrival times follows a specified form (Law, 2007). Considering the characteristics of patients arriving at the ED, we note that patients arrive independent of one another. Also, the number of arrivals fluctuate between hours of the day, and the number of arrivals in disjoint time intervals are independent (i.e. the number of patients arriving in a specific hour is independent of the number of patients that arrived in hour before). Law (2007) states that when these three conditions are met, a good way to model the arrival process is using a non-stationary Poisson process, in which the inter-arrival times between two patients are exponential distributed.

To model the arrival process of patients on the ED, we use time intervals of one hour. Within each time interval, we generate random points in time by generating inter-arrival times from an exponential distribution, based on the mean inter-arrival time of patients within that interval. To keep the amount of work manageable, we do not distinguish between different days of the week. This yields that the model outcomes represent an average day, however, it should be kept in mind that the effects are likely larger on Mondays and Fridays when the ED is more crowded (see Section 2.2). In Table 5.3, we provide an overview of the 24 distributions for the 7 days measurement in 2011 (Measurements, 2011; n=724).

Time interval	Exp(λ)	Time interval	Exp(λ)
$00^{00} – 01^{00}$	0:18:16	$12^{00} – 13^{00}$	0:08:24
$01^{00} – 02^{00}$	0:30:00	$13^{00} – 14^{00}$	0:10:30
$02^{00} – 03^{00}$	0:24:43	$14^{00} – 15^{00}$	0:08:14
$03^{00} – 04^{00}$	0:42:00	$15^{00} – 16^{00}$	0:06:34
$04^{00} – 05^{00}$	0:46:40	$16^{00} – 17^{00}$	0:07:38
$05^{00} – 06^{00}$	1:34:00	$17^{00} – 18^{00}$	0:08:56
$06^{00} – 07^{00}$	1:00:00	$18^{00} – 19^{00}$	0:14:29
$07^{00} – 08^{00}$	0:46:40	$19^{00} – 20^{00}$	0:13:08
$08^{00} – 09^{00}$	0:19:05	$20^{00} – 21^{00}$	0:11:21
$09^{00} – 10^{00}$	0:15:33	$21^{00} – 22^{00}$	0:12:44
$10^{00} – 11^{00}$	0:08:45	$22^{00} – 23^{00}$	0:15:33
$11^{00} – 12^{00}$	0:09:33	$23^{00} – 00^{00}$	0:17:30

Table 5.3: Mean inter-arrival times per hour of the day in 2011 (Measurements, 2011; n=724).

Processing times of triage and treatment

A commonly used probability distribution function to describe activity duration is the gamma(α,β)-distribution. Based on the processing times captured during our measurement, we determine that the processing times inside the *triage station* and the *treatment station* (or hallway bed) have the probability distributions as given in Table 5.4. We tested the distributions using the statistical Pearson Chi-Square test, by testing the null hypothesis that the processing times found in our measurement are an independent sample of the gamma distribution with the distribution parameters (α and β), as shown in Table 5.4. A detailed described of each of these analyses can be found in Appendix C.

Waiting time of laboratory blood test results

To simulate the time it takes before laboratory blood test results become available, we use *trace driven simulation* (Law, 2007). We establish a multinomial distribution with A_0, …, A_k classes of one minute time intervals (k = 183; and the number of minutes waiting corresponds with the value of *k*), N_k being the number of observations in class A_k (with ΣN_k = 439 observations from our measurement), and C_k the chance a certain patient (X) has to wait the number of minutes corresponding with class A_k ($C_k = P(X \in A_k)$). Then, by using the cumulative function of the chances per class, and a random number between 0 and 1, we can simulate the times patients have to wait before their laboratory tests results are available.

Moments of patients indirectly taken, and minimum waiting times of patients in waiting rooms

Patients who are taken indirectly to a room, first wait a certain time in the waiting room before they are taken to a room. By using the measurement data upon the time patients spend inside the waiting room before being taken indirectly, we derive that we can simulate this period of waiting time by an exponential distribution. Further, as explained in Section 5.2.4, we provide each patient with a minimum waiting time in the waiting rooms, for which we use gamma distributions. We provide an overview of these distributions and their parameters in Table 5.4, while a description of the underlying analyses we used to identify the probability distributions can be found in Appendix C.

Triage in triage room, when no blood is taken	Gamma(3.79, 1.49)
Triage in triage room, when blood is taken	Gamma(2.81, 2.87)
Time patients spend inside a treatment room (or hallway bed), when the patient receives no laboratory blood test	Gamma(1.79, 59.78)
Time patients spend inside a treatment room (or hallway bed), when the patient receives a laboratory blood test	Gamma(4.86, 34.89)
Time patient spend inside a treatment room (or hallway bed) during the night (between 23h15 and 07h30)	Gamma(4.63, 33.69)
Waiting time before patients are taken indirectly	Exp(9.96) + 2
Minimum waiting time of patients in waiting room 1	Gamma(1.17, 3.28)
Minimum waiting time of patients in waiting room 2	Gamma(0.46,17.36)

Table 5.4: Probability distribution functions of service and waiting times.

5.2.6 Flowcharts

To structure our model building, we created three flowcharts in which we captured all decision moments that need to be made inside our ED model. These flowcharts were used as a guide when we build our model step-by-step. The flowcharts are: one for the event when a new patients arrives; one for the event when a patients service or minimum waiting time at a station is finished and wants to be moved, and one to regulate the patient flow of patients taken *indirect* to a treatment room. The three flowcharts can be found in Appendix D.

5.2.7 Model validation

Validation is the process of ensuring that the created model is an accurate representation of the actual system (Rossetti, Trzcinski, Syverud, 1999). To validate our model we use two qualitative- and two quantitative techniques.

Validity of input data

An important aspect in any simulation is the validity of data used to build the model (Sargent, 1998; Samaha, Starks, Armel, 2003). In our model, we use the data obtained from our own measurement (Measurements, 2011). As described in Subsection 2.1.2, we designed two data collecting forms to obtain the desired data, at which the ED staff registered carefully selected moments in time. By using these predefined forms, we excluded subjectivity from our measurement. And as we further have no indications that staff behaved differently during the measurement (in literature referred to as the *Hawthorne effect*), we conclude that our input data is valid.

Validity of the model processes

To validate whether our model represents the ED in terms of processes (e.g. the way patient move throughout the ED, and the utility of hallway beds), we use a technique called *face validity* (Martis, 2006; Rossetti, Trzcinski, Syverud, 1999; Sargent, 1998). Face validation involves asking acknowledge persons (experts) about whether or not the model and its behavior are reasonable.

In one session with an ED physician, we validated our model assumptions, the flowcharts, our method used to simulate minimal waiting times of patients in the waiting rooms, and our control mechanism used towards usage of hallway beds. The ED physician confirmed the model being valid towards these aspects, with one remark. He suggested that the minimum waiting time of patients to placement in a room is likely to be higher when already 11 or 12 rooms are occupied, compared to for example when only 3 or 4 rooms are occupied, due to staff being more busier. We agreed and adjusted the model in such a way that the chance on a relative high minimum waiting time is higher when only two or three rooms are empty, and even higher when only one room is empty. This is achieved by drawing two random numbers, when two or three rooms are empty, and three random numbers when one room is empty, of which the highest is taken and used to derive a minimum waiting time from the probability distribution function as given Table 5.4.

Validation of the events

The third technique we use to validate our model is an (objective) quantitative technique, which Martis (2006) refers to as *event validity*. Within this technique, the occurrence of specific events in the simulation model is compared to historical data of the real system. By using this technique we test the model correctness upon 'the number of patients being taken indirectly to a treatment'.

To obtain the data to validate our model upon the number of patients taken indirectly, we run the model for 101 days and excluded the patients from the first day as warm up period (see paragraph *design experiments*). In Table 5.5 we provide an overview of the average number of patients taken indirectly during our measurement (column 2) and within the simulation model (column 3).

Group	Mean data measurement	Mean simulation	Difference
D9	18.1%	18.1%	0.0%
D10	19.3%	19.1%	-0.2%
D11	26.5%	26.6%	+0.1%

Table 5.5: Validation of indirect patients (Measurement, 2011; n=724; Simulation, 2011; n=10,398).

From Table 5.5, we conclude that the method we used to model the process of patients being taken indirectly to a treatment room is valid in terms of the number of patients that are moved indirectly.

Validation of output

Law (2007) states that the most definitive test of a simulation´s model validity is to establish that its output data closely resembles the output data that would be expected from the actual system. To test our output, we use our two performance measures; *waiting time to triage,* and *patient LOS,* and add a third measure; *waiting time to placement inside a treatment room after triage in the triage room*. We run the model for 101 days, from which we exclude the first day as warming up period, and use the Welch *t*-test to determine whether the model is an accurate representation of the actual ED system (Law, 2007). We construct a 95% confidence interval for $\mu_X - \mu_y$, in which μ_X represents the mean value of 7 days of actual data from our measurement, and μ_y the mean value of the 100 days simulated. When the value 0 is in the interval, this is equivalent to not rejecting the null hypothesis H_0: $\mu_X = \mu_y$, meaning that there is no reason to assume that the data obtained from our model differs significantly from the real data. In Table 5.6 we provide the sample means and confidence intervals.

Time period	Measurement (μ_X)	Simulation (μ_y)	95% C.I. for $\mu_x - \mu_y$	Significant different?
Waiting time to triage	7.28	6.95	[-0.74, 1.00]	No
Waiting time to placement room	13.54	11.02	[-0.87, 5.19]	No
Patient LOS, no blood test	132.27	121.22	[-11.37, 32.46]	No
Patient LOS, blood test	182.07	183.26	[-11.11, 5.01]	No

Table 5.6: Validation of wait- and throughput times (in minutes).

From Table 5.6, we conclude that our model is valid in terms of output data. However, note that the right hand side of the second confidence interval *waiting time to placement inside a treatment room* is much bigger than the fractions below zero. This indicates that our model is on average 'to positive' in terms of the times patients wait to be placed inside a room. Although this difference is not significant, we believe it influences the results of our intervention that we are going to test and therefore we will come back to this point in Section 5.4.

Concluding, based on all these validation aspects described in Subsection 5.2.7, the simulation model is determined being valid.

5.2.8 Design experiments

To obtain accurate simulation results, we need to specify the models *run length*, the *initial conditions of each run*, the *number of runs* needed to obtain sufficient performance measures output data, and the *warm-up period of the model.*

Run length

The simulations run length is the time of one simulation run. Important when determining the run length, is whether the system under investigation is a *terminating system*; meaning that a natural event specifies the length of a run (Law, 2007). As we are interested in the consequences of starting blood test in the triage room, and the triage room is only partly opened during the day (07h30-23h15), we conclude that our system under investigation is terminating with a run length of one day.

Initial conditions

Law (2007) states that the measures of performance for a terminating simulation depend explicitly on the state of the system at 'opening'; thus, care must be taken in choosing appropriate initial conditions. In our model, the initial conditions of each run are specified by the time treatment rooms remain occupied after 07h30 by patients who arrived during the night. But due to the stochastic arrival rate and stochastic treatment service times, the initial conditions are not same each day. A widely used heuristic approach to deal with changing initial conditions, is by actually simulating the activities that influence the values of the initial conditions (Law, 2007). Although the method has the disadvantage that activities need to be simulated that are not directly used, we decide to use this method, as we believe it provides the most reliable initial conditions for each run. In Subsection 5.2.4 we described the patient groups that arrive between 23h15 and 07h30, as well as the path they follow throughout the ED.

Number of runs

We decide that we want to determine the expected increase in *waiting time to triage*, within a confidence level of 95% (α=0.05) and a maximum error of 0.5 minutes, and the expected *decrease in patients LOS of patients receiving a blood test from the triage nurse* with a maximum error of 3 minutes. To achieve these demands, we determine that we need 413 runs of one day. Additional clarifications and the calculations can be found in Appendix E.

Now that we determined that we need 413 runs, we have two options. We can run 413 runs of 1 day plus 1 day warm-up (see next paragraph *Model warm-up*), equaling 413 runs of 2 days, or we can decide to run 414 days and delete the first day as warm-up. For practical reasons, we prefer the second option and decide to run our model in one long run.

Model warm-up

Our model starts at day 1 at midnight with an empty system. As normally the system is not empty at 0:00 at night, this might influence the initial conditions of the first day or perhaps first days. This period is called the model warm-up period (Law, 2007) and needs to be excluded from our output data analysis.

Welch (1981, 1983) state that the simplest and most general technique for determining the warm up period is a graphical procedure, in which the value of the parameter under consideration is plotted in time. We quantify the initial condition of each run, one day, by determining the 'total duration of treatment rooms being occupied after 07h30, by patients that were placed inside the rooms before 07h30´. To clarify, consider the following example. Let two patients be in a treatment room at 07h30 on a specific day, of whom we know that patient 1 arrived at 05h30 and patient 2 at 06h00. Further, both patients were immediately placed inside a treatment room at arrival and both have a treatment service time of 3 hours. Then the value of our initial condition on that specific day is the sum of 60 minutes (patient 1) plus 90 minutes (patient 2), so 150 minutes. In Figure 5.6, we provide an overview of the average value of the initial conditions.

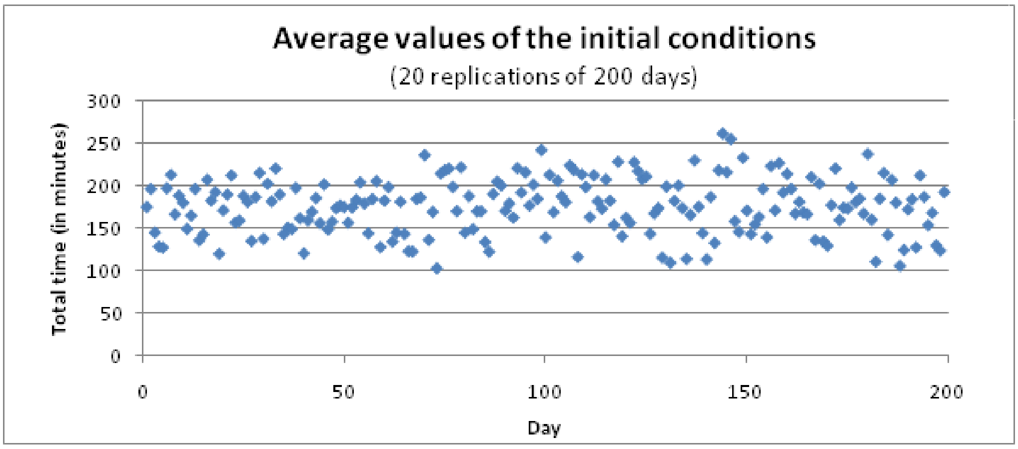

Figure 5.6: Values of the initial conditions.

Based on Figure 5.6 we conclude that the value of the initial conditions during the first days are not lower than during days later on. Nevertheless, based on the knowledge that the model starts at day 1 in an empty system, we decide to exclude the first day of each run.

5.3 Results

In Table 5.7, we provide an overview of the results, with in the first row the simulation output when the triage nurse does not starts patient's blood tests (*current situation*), and in the second row the simulation output when the triage nurse does starts blood tests during the triage (*intervention*). The group D10-A contains the subgroup of patients in D10 whose blood test is started by the triage nurse, while the remaining patients in D10 are referred to as D10-B (see Subsection 5.2.2).

Arrival distribution 2011 *Configurations*	*Average waiting time to triage*	*Average patient LOS of patients whose blood test is started by the triage nurse (D10-A)*
Blood tests <u>not</u> started by triage nurse	0:06:46	3:12:58
Blood tests started by triage nurse	0:08:04	3:05:17
Difference	+ 1m18s	- 7m41s
Percentage of all ED patients affected (between 07h30 and 23h15)	72%	16%

Table 5.7: Simulation output results.

From Table 5.7, we conclude that 72% of all patients attending the ED between 07h30 and 23h15 is affected by an average increase of 1 minutes and 18 seconds in waiting time to triage, when the triage nurse starts blood tests. Of 16% of all patients the blood tests are started by the triage nurse, and this results in an average decreasing patient LOS of 7 minutes and 41 seconds. Note that this 16%, is a subgroup of the 72% affected by the increased waiting time to triage.

To quantify the *indirect effect*, we use the average patient LOS of D10-B and the number of patients treated in hallway beds. The results are given in Table 5.8.

Arrival distribution 2011	*Average patient LOS of D10-B*	*Number of patients treated in hallway beds*
Blood tests <u>not</u> started by triage nurse	3:16:07	513
Blood tests started by triage nurse	3:17:53	405
Difference	+ 1m46s	- 21.1%

Table 5.8: Indirect effect.

Table 5.8 shows that the average patient LOS of patients in group D10-B increase with 1 minute and 46 seconds, when the triage nurse starts the blood tests. Including that the average waiting time to triage increased with 1 minute and 18 seconds due to this intervention (see Table 5.7), we have to conclude that in this group no *indirect effect* is seen within this group. However, this does not mean that there was no *indirect effect*, as clearly is shown by the number of patients treated in hallway beds. Due to patients occupying treatment rooms less long, the number of patients treated in hallway beds decreased with 21.1%.

5.4 Scenario analysis

To strengthen our analysis, we run our model with two additional scenarios. A third scenario investigating *the effects once the ED is part of the IEP* and *the closure of the ED Sportlaan for adult emergency care* is not included, because there are too many uncertainties. We consider the future situation in more detail in Section 5.5.

Scenario 1 Input arrival rate of 2010

In this first scenario we run our model with the input arrival distribution based on the arrival of patients in 2010 (SAP, 2010; n=40,541). We decided to include this scenario, because, with an average of 103 patients a day, the number of patients was relative low compared to the overall average of 111 patients a day in 2010. In Table 5.9, we provide an overview of the 24 distributions for the 365 days of 2010.

Time interval	Exp(λ)	Time interval	Exp(λ)
$00^{00} – 01^{00}$	0:20:36	$12^{00} – 13^{00}$	0:07:46
$01^{00} – 02^{00}$	0:31:12	$13^{00} – 14^{00}$	0:07:52
$02^{00} – 03^{00}$	0:38:46	$14^{00} – 15^{00}$	0:07:54
$03^{00} – 04^{00}$	0:52:01	$15^{00} – 16^{00}$	0:07:55
$04^{00} – 05^{00}$	0:54:53	$16^{00} – 17^{00}$	0:07:52
$05^{00} – 06^{00}$	1:01:52	$17^{00} – 18^{00}$	0:09:10
$06^{00} – 07^{00}$	0:59:21	$18^{00} – 19^{00}$	0:09:47
$07^{00} – 08^{00}$	0:39:15	$19^{00} – 20^{00}$	0:09:55
$08^{00} – 09^{00}$	0:20:12	$20^{00} – 21^{00}$	0:10:21
$09^{00} – 10^{00}$	0:10:44	$21^{00} – 22^{00}$	0:11:08
$10^{00} – 11^{00}$	0:08:38	$22^{00} – 23^{00}$	0:13:01
$11^{00} – 12^{00}$	0:07:53	$23^{00} – 00^{00}$	0:19:02

Table 5.9: Mean inter-arrival times per hour of the day in 2010 (SAP, 2010; n=40,541).

In Table 5.10, we provide the results of running the simulation model with the input arrival distributions based on the data of 2010.

Arrival distribution 2010 *Configurations*	*Average waiting time to triage*	*Average patient LOS of patients whose blood test is started by the triage nurse (D10-A)*
Blood tests not started by triage nurse	0:07:16	3:15:34
Blood tests started by triage nurse	0:08:50	3:07:16
Difference	+ 1m34s	- 8m18s

Table 5.10: Simulation output results of scenario 1.

From the Tables 5.7 and 5.10 we conclude that the average increase of 8 patients a day results in an increased waiting time to triage of 16 seconds, and an average decrease of 37 seconds in patient LOS of the patients who received a blood test by the triage nurse. Further, considering the *indirect effect*, also in this scenario the *indirect effect* is observed (see Table 5.11). The total number of patients treated in hallway beds decreased with 15.7% when the triage nurse starts blood tests, while the increase in patient LOS of D10-B is with a difference of only 57 seconds approximately as large as the increase in waiting time to triage.

Arrival distribution 2010	*Average patient LOS of D10-B*	*Number of patients treated in hallway beds*
Blood tests not started by triage nurse	3:14:20	781
Blood tests started by triage nurse	3:17:08	658
Difference	+ 2m48s	- 15.7%

Table 5.11: Indirect effect in scenario 1.

Scenario 2 Average minimum waiting time to placement of 13 minutes and 32 seconds

During our validation we found that our model seems relative 'positive' in terms of waiting times. Especially the waiting time to placement inside a treatment room is of major influence on the time that can be saved by our intervention (see *W2* in Figure 5.2). From Table 5.6, we know that the average time patients waited inside a treatment room after being triaged was 13 minutes and 32 seconds during our measurement, however, our model´s average is 11 minutes and 01 seconds. As the difference is +23%, we run the model with a scenario in which all waiting times to placement are increased by 23%. Further, we use the input distribution of 2010, as we belief this distribution represents reality better than the 'relative low' distribution of 2011. The results are shown in Table 5.12 and Table 5.13.

Arrival distribution 2010 *Configurations*	*Average waiting time to triage*	*Average patient LOS of patients whose blood test is started by the triage nurse (D10-A)*
Blood tests not started by triage nurse	0:07:15	3:17:42
Blood tests started by triage nurse	0:08:40	3:08:14
Difference	+ 1m25s	- 9m28s

Table 5.12: Simulation output results of scenario 2.

From Table 5.12 we conclude that the average patient LOS of patients whose blood test is started by the triage nurse can be decreased by 9 minutes and 28 seconds. However, due to the increased work that the triage nurse needs to conduct, the average waiting time to triage increases with 1 minutes and 25 seconds.

Arrival distribution 2010	*Average patient LOS of D10-B*	*Number of patients treated in hallway beds*
Blood tests not started by triage nurse	3:16:15	769
Blood tests started by triage nurse	3:17:59	668
Difference	+ 1m44s	-13.1%

Table 5.13: Indirect effect in scenario 2.

Alongside the decreased patient LOS of approximately 10 minutes of patients whose blood test is started, also the total number of patients treated in hallway beds decreased with 13.1% (*indirect effect*; see Table 5.13). However, the effect is not seen in reduced patient LOS of the patients in D10-B, as the LOS of this group of patients increased with an average 19 seconds above the 1 minute and 25 seconds average increased waiting time to triage.

5.5 Simulation conclusions

We place our conclusions upon the system with the configurations as described in *scenario 2*, as we believe these represent the reality best. We conclude that when blood tests are started by the triage nurse:

- the average waiting time to triage increases with 1 minute and 25 seconds, from 7 minutes and 15 seconds to 8 minutes and 40 seconds, an increase that affects 72% of all patients[6].

- the number of patients of whom their triage is not started within the 10 minute norm (NVSHV, 2008; Prins, 2011) increases from 23.9% to 28.7%, an increase of 4.8%.

- the number of patients treated in a hallway bed decrease with 13.1%.

- the average length of stay of patients whose blood test is started by the triage nurse (D10-A) decreases by 9 minutes and 28 seconds, a decrease for 16% of all patients[6]. Further, due to the increased waiting time to triage the average length of stay of 42% of all patients increases with 1 minutes and 25 seconds, and 14% faces an average increase in patient LOS of 1 minute and 44 seconds. The remaining 28% of the patients faces no difference in their average patients LOS, as their treatment is always directly started at arrival (see Subsection 5.2.4). The results are shown in Table 5.14.

Patient group	*Difference in average patient LOS*	*Fraction of all patients*[4]
D1 to D8	0	28%
D9 and D12	+ 1m25s	42%
D10-A	- 9m25s	16%
D10-B and D11	+ 1m44s	14%

Table 5.14: Effect on patient LOS of patients when the triage nurse starts blood tests.

Now it is up to the management of the RVE acute care to decide whether they accept an increased waiting time to triage of 1m25s, to gain a decrease in patient LOS of 9m25s for 16% of all patients and a 13% decrease in the number of patients treated in hallway beds. We believe the increased patient LOS of 1m25s and 1m44s are significant small considering that the average patient LOS are 2 to 3 hours, and therefore do not have to be included in this decision.

Assessment

We recommend to adopt this intervention, as we believe that especially the benefits of a 13% reduction in hallway beds outweigh the disadvantage of an average 1m25s increase in waiting time to triage. In this decision, we also included that the intervention is easy to implement, no costs have to be made, and that the benefits of this intervention are the highest during the *most critical moments*, namely the moments of crowding.

To clarify this last argument, note that the simulation results are <u>overall</u> averages. The 9m28s time saving found is the average of all times saved during both crowded and non crowded moments. Although also during non crowded moments the blood tests are requested some minutes earlier

[6] *All patients attending the ED between 07h30 and 23h15.*

compared to situation in which the patient is first taken to a treatment room, the advantage of the triage nurse starting the blood test is relative small. During crowded moments on the other hand, the advantage of the triage nurse starting blood tests is significant larger, as the waiting time between triage and placement in a treatment room is much longer. Therefore, especially during the most *critical moments* the benefits of this intervention are the highest.

But what are the advantages and disadvantages of the triage nurse starting patient's blood tests when the ED, a GP post and the new AADU are going to cooperate in the IEP? And what are the consequences when the ED Sportlaan is closed for adult emergency care?

Unfortunately we cannot determine the exact effects, as we lack information to run a reliable future scenario. For example, the probability distribution functions we used in our model to simulate *the time patients spend inside a treatment room* likely become invalid. The cardiology is going to work with two residents during the day instead of one (our *capacity vs demand* analysis contributed to this decision!); two additional treatment rooms become available on the medium/high care; and the number of patients send to the larger AADU increases (see Subsection 2.6.1). All these changes influence the time patients spend inside a treatment room, but we do not know how much.

Nevertheless, we expect that having the triage nurse starting blood tests also benefits in the future situations; when *the ED becomes part of the IEP* and *when the number of patients attending the IEP increase*. Patients still need blood tests, and, also in the IEP it will be likely that many patients have to wait after triage to be placed in a treatment room. Therefore, placing the times patients wait *for their blood test results* and *for placement in a room* in parallel will save time, and, as these patients occupy the rooms less long, the number of hallway beds needed decreases (see Subsection 5.1).

But what is the effect on the waiting time to triage? We expect that the waiting time to triage increases, as more patients have to be triaged by the triage nurse. From Subsection 2.6.2 we know that when the ED Sportlaan is closed for adult emergency care the number of patients increases with an expected 4,770 patients a year, and this number might increase when also other EDs in the region are *closed*, *closed during specific parts of the day* or *closed for specific patient groups* on pressure of health insurers (Prins, 2012). In addition, we expect that the flow of *indirect* patients decreases. In the IEP the triage will also be used to divide the incoming flow of patients towards the GP post and the ED (see Section 2.6), and therefore it is assumable that less patients are taken out of the waiting room before being triaged. All these changes yield that more patients need to pass the triage room, and this likely results in an increase in waiting time to triage, as well as the number of patients of whom the triage is not started in the 10 minute norm increases (NVSHV, 2008; Prins, 2011).

To prevent that the triage nurse becomes a bottleneck of significance in the future, we recommend to investigate whether the accessibility of triage remains within acceptable limits, each time a significant change takes place in patient flows. And when the waiting time becomes unacceptable, we recommend to investigate alternative solutions, e.g. deployment of a second triage nurse, as we showed that starting blood tests earlier in the process clearly benefits.

Concluding, we recommend to adopt this intervention, but with the remark that additional research is needed to determine whether the triage nurse does not become a bottleneck of significance when patient flows change.

Chapter 6 Conclusions and recommendations

In Section 6.1, we provide our research conclusions by answering our research questions. Section 6.2 contains the interventions we recommend to reduce waiting times, and in Section 6.3, we describe our recommendations for further research.

6.1 Conclusions

The emergency department (ED) Leyweg of HagaZiekenhuis experiences problems with long waiting times, resulting in dissatisfaction among staff and patients. To deal with these problems, both management and staff desires quantitative insights in the waiting times and their causes, as well as they would like to obtain suggestions for interventions to reduce the patient length of stay (LOS) by reducing delays. As this request consists of two parts, we define our research objective in twofold:

Objective 1 *Provide insight in the throughput process of the emergency deparmtent, by mapping the main patient flows, the activities performed on the patients, the delaying factors in the process, and determine the duration of both activities and waiting times;* and

Objective 2 *Recommend interventions to reduce the patient length of stay, by identifying and analyzing possibilities to reduce delays.*

To achieve these objectives, we use four research questions. The first question is used to achieve *objective 1*, and the questions 2, 3, and 4 to achieve *objective 2*.

RQ1 *<u>What are the EDs input, throughput and output patient flows, and what are the current activity durations and waiting times on the ED?</u>*

We analyzed the main input flows, throughput processes, output flows, and allocation and usage of resources in detail, and conducted a time measurement study to obtain quantitative information upon the activity durations and waiting times between activities (see Chapter 2). In total, we identified twenty six delaying factors, and we believe that the delays caused by 'doctors not being available' and 'waiting time to laboratory tests results' provide the best opportunities to focus on with interventions, as these delaying factors often cause long waiting times and affect many patients. However, due to the stochastic character with which delays occur, we decide not to only focus on identifying interventions to reduce large delays, but for as many delays as possible. An overview of all *quantified* and *not quantified* delays can be found in Table 6.1 and Table 6.2 respectively, both presented on the next page.

RQ 2 *<u>Which literature can we use to determine interventions?</u>*

Numerous reports are written on identifying and eliminating delays in EDs, but there is no strategy or guidance available to identify interventions that guarantee to be effective. Causes of delays differ between EDs, and even when the main delaying cause is the same at two EDs, contextual factors can cause that a successful intervention at one ED fails at the other. We conclude that a design study is needed in which we use a customized approach to identify and test promising interventions. To identify these promising interventions, we use insights from *factory physics, lean manufacturing,* and *capacity management* (see Section 3.2).

	Waiting for:	Average waiting time (min)	Coefficient of variation	Patients affected
DF_3	Triage nurse	7	0.90	72%
DF_4	Placement in treatment room (after triage)			
	- Low care	25	1.78	34%
	- Medium/ high care	14	1.27	24%
DF_6	Inter collegial consult doctor	24	0.94	… %[A]
	External actors to depart			
DF_8	- Admissions[B]	24	1.25	30%
DF_9	- Ambulance or lay cab	63	0.67	2%
DF_{10}	- Crisis service	98	0.35	1%
DF_{11}	Availability co-assistant or doctor[C]			
	- Low care	10	1.50	46%
	- Medium/ high care[D]	32	1.28	52%
DF_{15}	Laboratory test results			
	- Blood tests	47	0.79	52%
	- Urine tests	36	0.81	15%
	Radiology diagnostic tests			
DF_{17}	- X-ray picture	10	0.70	29%
DF_{18}	- CT-scan[E]	34	0.86	8%
DF_{19}	- Ultra sonogram[E]	22	1.13	7%

[A] Value is unreliable; [B] Between 07h30 and 17h00; [C] Measured from the moment the nurse is finished with the patient; [D] Exclusive patients treated in trauma room 1; [E] Between 08h00 and 18h00.

Table 6.1: Overview of quantified delaying factors (Measurements, 2011).

	Cause of waiting
DF_1	The productivity of staff decreases by increasing levels of frustration and discussion these frustrations, caused by *illegitimate* patients attending the ED.
DF_2	The service time of triage is in 42% longer than the maximum 5 minute norm (NVSHV, 2005).
DF_5	The patient throughput process is delayed when doctors must wait for their consult with a supervisor, or wait for the supervisor to arrive at the ED.
DF_7	Patients treatment is not always started when doctors are at the end of their working shift.
DF_{12}	Productivity of staff decreases as patients or patients guests ‘disturb’ them with questions.
DF_{13}	Time is wasted by relocating patients through and from hallway beds.
DF_{14}	Laboratory test results are not immediately used when available.
DF_{16}	Patients are not transported to the X-ray room, while the X-ray room is idle and patients are waiting for an X-ray.
	Shortage of doctors capacity of:
DF_{20}	- internal medicine with *undercapacity* between 17h30 and 0h00 on weekdays.
DF_{21}	- cardiology with *undercapacity* between 10h00 and 20h00 on weekdays.
DF_{23} **DF_{24}**	- general surgery with *undercapacity* between 17h00 and 0h00 on weekdays and between 12h00 and 14h00, 16h30 and 21h00 and 23h00 and 01h00 during the weekends
DF_{22}	The ‘back-up’ resident of the cardiology is called too late and not always available.
DF_{25}	The ‘back-up’ resident of the general surgery is not always available and often the *youngest* resident is send to the ED. This resident is commonly inexperienced and needs of a lot of supervision and consultations, with the result that throughput does not increase.
DF_{26}	We found indications that the nursing capacity is short during lunch and supper breaks.

Table 6.2: Overview of delaying factors not quantified.

RQ3 *Which interventions can we suggest to reduce waiting times and how can we assess them?*

Using the insights from literature, we identify sixteen promising interventions (see Table 4.1), which we divide in two groups based on whether we need extensive additional research to assess them or not. Ten of these interventions are categorized as *suggested interventions not in need of extensive additional research*, and we investigate each one in Chapter 4. To assess them, we judge them on a combination of *costs*, *feasibility* ('the degree with which changes have to be made towards the EDs lay-out, ICT systems used, and in the way staff works'), and *intervention specific* pros and cons.

However, as we are limited by time, we are unable to investigate also the six *suggested interventions in need of extensive additional research*. In consultation with an ED physician and the manager of the RVE acute care we identified the intervention of 'starting blood tests by the triage nurse' as the most promising, as we perceived significant benefits in terms of patient LOS reduction, no external actors have be involved to realize this intervention, and no costs have to be made. We decided to investigate this intervention in detail using a simulation study. In Table 6.3 we provide an overview of our simulation results, while a description of our simulation can be found in Chapter 5.

Configurations	*Average waiting time to triage*	*Number of patients of whom the triage is not started within the 10 minute norm*	*Average patient LOS of patients whom blood test is started by the triage nurse*	*Number of patients treated in hallway beds (scenario 2)*
Blood tests not started by triage nurse	0:07:15	23.9%	3:17:42	769
Blood tests started by triage nurse	0:08:40	28.7%	3:08:14	668
Difference	+ 1m25s	+ 4.8%	-9m28s	-13.1%

Table 6.3: Results simulation study.

We conclude that when the triage nurse starts blood tests, the waiting time to triage increases with an average of 1m25s, affecting 72% of all patients, and causing an increase of 4.8% of patients of whom their triage is not started within the norm of 10 minutes after arrival (NVSHV, 2008; Prins, 2011). But considering the advantages, we conclude that 16% of all patients benefit from an average decrease of 9m28s in their patients LOS as a direct results of their blood tests being started by the triage nurse, while the number of patients treated in hallway beds reduces with 13.1%.

Although it is up to the management team of the ED to decide whether they believe the increased waiting time to triage is accessible, we believe that especially the benefits of a 13% reduction in hallway beds outweigh the disadvantage of an average 1m25s increase in waiting time to triage. And when we also include that the intervention is easy to implement, no costs have to be made, and the highest benefits are obtained during the moments in which time savings are most desired: the moments of crowding (see Section 5.5), we decide to recommend to adopt this intervention.

RQ 4 *Which interventions do we recommend?*

We conclude that eleven of the suggested interventions provide good opportunities for the ED to reduce waiting times, resulting in eleven recommendations (see Section 6.2). The five *suggested interventions in need of extensive additional research* which we did not further investigate are recommended as options for additional research (see Section 6.3).

6.2 Recommendations

Recommendation 1 Modify the working schedule of the residents of the internal medicine during weekdays towards having one resident started at 12h00 instead of two at 08h30, and start a test pilot to determine the effect.

Our contextual analysis provides several indications that the capacity of the residents working for the internal medicine can be allocated more efficiently (see Subsection 4.1.1 for a detailed overview and clarifications). Therefore, to use the capacity more efficient, we recommend the internal medicine to change the working shifts of their residents. Instead of two residents starting in the day shift at 08h30, only one resident works the day shift from 08h30 to 17h00, while the second should works a *new* shift from 12h00 to 20h30. However, as we are unsure of the actual effects, we recommend to first start a test pilot to determine the effects.

Recommendation 2 Schedule an additional resident of the cardiology in a new shift from 10h00 to 18h30 during weekdays and start a test pilot to determine the effect.

Throughout our contextual analysis we obtained strong indications that the available resident capacity of the cardiology is insufficient during weekdays (see Subsection 4.1.2 for a detailed overview and additional clarifications). With permanent only one resident available, it is not possible to allocate capacity more efficient, resulting in our recommendation to schedule an additional resident during the most crowded moments in a *new* shift from 10h00 and 18h30. However, as we are unsure of the actual effects, we recommend to first start a test pilot to determine the effects.

Recommendation 3 Start diagnostic blood tests by the triage nurse.

We investigated this intervention in detail using a simulation study. Both the simulation conclusions and our motivation to recommend this intervention, can be found in Section 6.1.

Note that we tested this intervention using *system configurations* and *data* of the current situation in our simulation. When the ED becomes part of the IEP and the ED is closed for adult emergency care in the future (see Section 2.6), the effects might change. Therefore, we recommend this intervention with the remark that additional research is needed when patient flows change, to determine whether the *waiting time to triage* remains acceptable (see Section 5.5).

Recommendation 4 Residents must join co-assistant during first patient visit.

To minimize the delays caused by co-assistants preceding residents, residents should join their co-assistant during the first patient visit. The co-assistant can conduct his/her anamnesis and write his/her findings in the EPR, but the resident can immediately check the co-assistants work and provide possible useful instructions, as well as start diagnostic tests directly if necessary (see Subsection 4.2.1).

Recommendation 5 Place patients of the same specialty as much as possible in rooms near each other.

To save time by reducing *unnecessary movement* of staff, patients for the same specialties should be placed in rooms closely to one another as much as possible. Based on the locations of the computers commonly used by the internal medicine, neurology and cardiology residents respectively, we suggest to use the three hall treatment rooms (plus *trauma room 2* during crowding moments) for the neurology and general surgery patients, the beds one to four of the emergency cardiac care for the internal medicine and the beds five to ten of the emergency cardiac care for the cardiology. Note, we do not suggest to dedicate these rooms to a specific specialty, only to group patients if possible (see Subsection 4.2.2).

Recommendation 6 Doctors should start a patients treatment also when they are near the end of their working shift.

We believe that lack of efficient communication and information sharing should not be an accepted reason for not starting patients treatments (Interviews, 2011). And even though the patient might need to tell specific aspects twice, or a physical anamnesis is performed twice, we believe the advantages of time saved by for example starting diagnostic tests outweigh these drawbacks. Therefore, we suggest that doctors should start a patient treatment also when they are near the end of their working shift (see Subsection 4.2.3).

Recommendation 7 Send patients to the AADU earlier.

Currently, patients are not send to the AADU before all tests are done and a complete diagnosis and treatment is set. To gain time, we recommend that a patient, who does not need an X-ray picture, is send to the AADU at the moment it is decided to admit the patient (see Subsection 4.2.4).

Recommendation 8 Enhance the initiative of X-ray technicians.

Conversations with X-ray technicians should be started to enhance the initiative of some of them. Technicians should be encouraged to get the next patient when the X-ray room is idle, instead of waiting for the patient to be brought (see Subsection 4.2.5).

Recommendation 9 Provide doctors easy access to information on whether test results are available.

Screens should be located on strategic places on the ED, showing an overview of all patients present on the ED, with status updates towards diagnostic test results availability (i.e. laboratory test, CT-scans, ultra sonograms and X-ray pictures). In this way, doctors do not have to open EPRs each time to check whether the results are available and it is likely that the time test results remain unused decreases (see Subsection 4.3.1).

Recommendation 10 EPRs not in use should automatically change to status ‘read only’.

SAP software needs to be modified in such a way that EPR statuses are automatically changed towards ‘read only’ when no modifications are made in the record during a minute. This prevents that time of doctors and nurses is wasted by searching for EPRs being left open on computers (see Subsection 4.3.2).

Recommendation 11 Inform patients more actively by frequent short visits.

Nurses and doctors should inform patients more frequently by short visits. In this way, fewer patients become restless and less staff is ‘disturbed’ with questions (see Subsection 4.4.1).

6.3 Further research

This report contains a comprehensive descriptive and quantitative analysis of ED processes, from which we also derive opportunities for additional research. We identify five opportunities for additional research, which we describe in the Subsection 6.3.1 to 6.3.5.

6.3.1 Investigate the accessibility of the cardiology outpatient clinic

We perceive that the outpatient clinic of the cardiology has capacity problems. General practitioners send patients to the ED when they cannot be seen within a short time period at the outpatient clinic (Conversation nurses, 2011). However, according to the ED nurses and ED physicians these patients are *illegitimate* users of ED resources, resulting in frustration among staff (see DF_1). One of the ED nurses estimates that 20-30% of all patients attending the ED for the specialty cardiology belongs to this group.

To tackle this problem, strict criteria need to be formulated defining which patients are *illegitimate* users, and a measurement should be started to determine the number of *illegitimate* patients of the cardiology attending the ED. When high numbers of *illegitimate* users are found, the accessibility of the outpatient clinic should be investigated, e.g. towards the efficiency of planning appointments.

6.3.2 Improve the accessibility of supervisors

We observed that the patient throughput process is delayed when doctors must wait for their consult with a supervisor, or wait for the supervisor to arrive at the ED (see DF_5). Although we did not quantify these delays in our research, we believe that reducing them has a significant impact on the patient LOS of individuals currently faced by these delays.

6.3.3 Reduce waiting times for external actors

In our context analysis, we identified long delays before some groups of patients can depart. From Section 2.4, we know that 30% of all patients wait on average 24 minutes to be admitted (see DF_8), 2% waits on average 63 minutes for an ambulance or lay cab (see DF_9) and 1% waits on average 98 minutes for a consult with the crisis service (see DF_{10}). All activities for these patients are finished, meaning that each reduction in waiting time results in a similar reduction in patient LOS.

6.3.4 Digitize requests for X-rays, CT-scans and ultra sonograms

In Subsection 2.5.2, we described the process of requesting an X-ray in detail. We determined that there is a delay between the decisional moment of a doctor to make an X-ray and the moment the test is actually started (see DF_{17}). Currently, to request an X-ray, a request form needs to be taken, filled in, signed by the doctor, and the form needs to be brought to the X-ray room. According to the philosophy of lean, unnecessary motion in the working processes of staff is a *waste* and should be eliminated. In here, the time it takes to walk to the X-ray room with the form, and back afterwards, is unnecessary motion and *wasted* time.

But also in the process of requesting CT-scans and ultra sonograms time is wasted. After the resident has called with the radiologist to receive permission, the requesting process would be faster if the resident can digitally request a time in the schedule of the radiology department. In this way, it saves one, two or three phone calls, plus the time each caller has to wait until the phone is picked up.

Concluding, it is very likely that time will be saved when X-rays, CT-scans and ultra sonograms could be digitally requested, however, additional research is needed to investigate the feasibility of this intervention. Currently, there is no digital diagnostic test requesting system, so this system must entirely be designed, developed and build.

In addition, we believe that especially when this intervention is combined with *recommendation 9*, the process of requesting and obtaining test results will save time. Having one or two screens providing all information upon diagnostic tests requested and test results available, the workload of staff decreases and time is saved, while also the patient LOS likely decreases by reduced delays.

6.3.5 Digitize the process of finding an inpatient bed

Digitize the process of finding an inpatient bed provides an opportunity for improvement. Currently, it takes on average 16 minutes and 39 seconds to find an inpatient bed between 07h30 and 17h00 (Measurements, 2011; n=79; CV=1.34), which is caused by at least five phone calls that need to be made between several actors (see Figure 2.11). We believe that with a *bed management system* for most patients an inpatient bed can be found within seconds, by reducing the unnecessary steps in terms of unit-to-unit communication. All wards, the AADU, the ED and the admission office should be connected, making fast information exchange possible, and thus the information about bed availability easily and quickly accessible.

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List of appendices

Appendix A Inaccuracy in departure time registration

The moments patients depart the ED are not accurately registered in the electronic patients records (EPRs) of patients (Observations, 2011; Measurements, 2011). Table A1 provides the average inaccuracy in departure time registration during our measurement. These times are obtained by comparing the end time registered in the EPRs, with the end times registered on the time registration forms during our measurement. We used the following formulae:

$AI_j = \sum_{i=1}^{n_j} S_{ij} - M_{ij}$, with

AI_j average inaccuracy in departure time registration of specialty *j*

S_{ij} end time registered in SAP of patient *j* treated by specialty *i*

M_{ij} departure time registered on the measurement forms of patient *j* treated by specialty *i*

n_j total number of patients treated by specialty *j*

Specialty	n=	Average inaccuracy in departure time registration *(hh:mm:ss)*
General surgery	386	00:17:50
Cardiology	104	00:19:40
Internal medicine	111	00:19:53
Neurology	47	00:25:55
Others	62	00:21:15

Table A1: Inaccuracy in registration moment of patient departure EPRs (Measurements, 2011; n=710).

Appendix B Modeling the indirect patients

The group of indirect patients consists of patients who based on their 'properties' should have been triaged in the triage room (see Table 5.1 in Chapter 5), however, are taken to be treatment room before being triaged by the triage nurse. In Table A2, we provide an overview of the percentage of patients within each group that is taken indirectly to a treatment room. To clarify, e.g. of all D9 patients attending the ED, 18.13% is taken to a treatment room before triage.

Group	Percentage of indirect patients **within** group
D9	18.13%
D10	19.26%
D11	26.51%

Table A2: Indirect patient groups.

To model the groups of *indirect patients*, we provide each patient in D9 with one 'indirect time' (IT1) and each patient in D10 and D11 with two indirect times (IT1 and IT2) using the distribution function we derived from the times patients waited to be taken indirectly during the measurement. Independent of the patient group, we check at time IT1 whether the patient is still in the waiting room. If this is the case, we determine the percentage of patients (group specific) that have already been taken indirectly out of the waiting room. In case this percentage is below the threshold value provided in Table A2, D9 patients are always accepted as indirect patient (they leave the model), while D10 and D11 patients are accepted when a treatment room is available. If the percentage is above the threshold value, the patient is not taken indirectly and remains in the waiting room.

Because the patients of D10 and D11 might not be taken indirectly caused by lack of treatment room availability, we provided each patients with two 'indirect times' by which we create a time interval in which they can be taken indirectly. When during this time interval a treatment room becomes empty (and no patients are laying in a hallway bed), the patient is still taken from the waiting room and placed in the treatment room. In Subsection 5.2.7 *Validation* we show that by using this method, we are able to accurately simulate the different fractions of patient groups.

Appendix C Motivation input distributions

In this appendix, we determine the probability distribution functions (PDF), which we need in our model. To determine the PDFs, we use the following three steps (Law, 2007):

Step I: Hypothesize families of distribution.
Step 2: Estimate parameters.
Step 3: Determine how representative the hypothesized distribution is.

(I) Time patient spend inside treatment room (or hallway bed), when the patient receives NO laboratory blood test

Step 1: Hypothesize families of distribution

We provide a summary of the data of our measurement in Table A3.

Descriptive statistics		Kurtosis	2.96
Mean	107.20	Skewness	1.52
Standard Error	11.80	Range	364
Median	89	Minimum	8
Mode	110	Maximum	372
Standard Deviation	80.05	Sum	4,931
Sample Variance	6,407.85	Count	46

Table A3: Data summary of the time patients spend inside a treatment room (or hallway bed) when the patient receives NO laboratory blood test.

Table A3 shows that the skewness is > 0, so the distribution is skewed to the right. Further, the coefficient of variation ($CV=\sigma/\mu$) ≈ 0.75, so the underlying PDF of these data could be a gamma or weibull with an $\alpha > 1$ (as the $CV < 1$). A commonly used PDF for activity duration is the gamma distribution. Therefore, we hypothesis that the underlying distribution is a gamma distribution.

Step 2: Parameter estimation

The parameters of the gamma distribution are *alpha* (α) and *beta* (β), and both parameters are part of the mean and variance (see equations 1 and 2).

Equation 1 Mean (μ) = $\alpha * \beta$

Equation 2 Variance (σ^2) = $\alpha * \beta^2$

To determine the values of *alpha* and *beta*, we rewrite the equations to one equation with one unknown variable (from Table A3 we known the values of the *mean* and the *standard deviation*). From equation 1 we derive that $\alpha=\mu/\beta$, and we use this equation to determine that $\sigma^2=(\mu/\beta)*\beta^2$, equaling $\beta=\sigma^2/\mu$. Now, we can calculate β, and once β is found, α can easily be found using equation 1. The parameters of the gamma distribution are: **α = 1.79, and β = 59.78**.

Step 3: Checking fit between perceived PDF and actual data

To check the fit between the gamma distribution and the actual data (X_1, …, X_n), we use the Pearson Chi-Square test. The formulae used to calculate the Chi-Square value (χ^2) is:

$$\chi^2 = \sum_{j=1}^{k} \frac{(N_j - np_j)^2}{np_j}$$

with k the number of bins, N_j the number of X_i's in bin j, and np_j the expected number of X_i's in bin j if we were sampling from the gamma distribution. To determine the number of bins needed we use the guideline of Law (2007), which states that:

Rule 1: the bin sizes should be chosen in such a way that the expected proportion of X_i's in each bin j has an equal chance (p_j),

Rule 2: the number of bins should be at least 3 ($k \geq 3$), and

Rule 3: the expected number of X_i´s should be at least 5 ($np_j \geq 5$).

Here, we choose to use 7 intervals (k=7), with p_j = 1/7 = 0.143 (for all bins; j=1,..,7). In this way, we meet the first two rules, and also the third rule is met as with n=46, the value of np_j = 6.57 (46*0.143). Further, we test H_0:p_1=p_2=…=p_7 (with α=0.05), and use the INV.GAMMA function of Excel to determine the begin and end points of the bins. In Table A4, we provide an overview of all values.

Bin	Start	End	np_j	N_j	$(N_j - np_j)^2/np_j$
1	0.0	32.45	6.57	8	0.31
2	32.45	53.79	6.57	1	4.72
3	53.79	75.88	6.57	11	2.98
4	75.88	101.51	6.57	5	0.38
5	101.51	134.82	6.57	10	1.79
6	134.82	187.82	6.57	6	0.05
7	187.82	∞	6.57	5	0.38
Value Chi-Square					10.61

Table A4: Overview of Chi-Square test results.

The Chi-Square table of critical points provides that the critical value is 12.59 (df=6). Therefore, as 10.61 < 12.59, we do not reject H_0.

Conclusion: there is no reason to assume that the *service time in a treatment room when the patient receives no laboratory blood test,* is poorly fitted by the gamma(1.79, 59.78)-distribution.

(II) Time patients spend inside a treatment room (or hallway bed), when the patient receives a laboratory blood test

Step 1: Hypothesize families of distribution

In Table A5, we provide a summary of the data of our measurement.

Descriptive statistics		Kurtosis	-0.55
Mean	158.85	Skewness	0.16
Standard Error	3.89	Range	293
Median	155	Minimum	17
Mode	150	Maximum	310
Standard Deviation	62.84	Sum	41,459
Sample Variance	3,949.37	Count	261

Table A5: Data summary of the time patients spend inside a treatment room (or hallway bed) when the patient receives a laboratory blood test.

Table A5 shows that the skewness is > 0, so the distribution is skewed to the right. Further, the coefficient of variation (CV=σ/μ) ≈ 0.40, so the underlying PDF of these data could be a gamma or weibull with an α > 1. Also in here, we hypothesis that the underlying distribution is a gamma distribution.

Step 2: Parameter estimation

Using the same method described in the paragraph above, we determine the parameters *alpha* (α) and *beta* (β): **α = 4.86**, and **β = 34.89**.

Step 3: Checking fit between perceived PDF and actual data

Again, we test a perceived gamma distribution, so we use the Pearson Chi-Square test as we described earlier. We use k=17, p_j = 1/17 = 0.0588 (for j = 1, …, 17), and test H_0:p_1=p_2=…=p_{17} (with α=0.05). We provide an overview of all values in Table A6.

Bin	Start	End	np_j	N_j	$(N_j - np_j)^2/np_j$
1	0.0	69.08	16.29	17	0.03
2	69.08	86.08	16.29	19	0.45
3	86.08	99.25	16.29	8	4.22
4	99.25	110.82	16.29	16	0.01
5	110.82	121.60	16.29	10	2.43
6	121.60	132.02	16.29	11	1.72
7	132.02	142.37	16.29	13	0.67
8	142.37	152.88	16.29	19	0.45
9	152.88	163.78	16.29	11	1.72
10	163.78	175.32	16.29	19	0.45
11	175.32	187.81	16.29	16	0.01
12	187.81	201.71	16.29	11	1.72
13	201.71	217.74	16.29	19	0.45
14	217.74	237.19	16.29	12	1.13
15	237.19	262.92	16.29	15	0.10
16	262.92	303.74	16.29	14	0.32
17	303.74	∞	16.29	15	0.10
				Value Chi-Square	15.98

Table A6: Overview of Chi-Square test results.

From the Chi-Square table of critical points we derive that the critical value is 26.30 (df=16). Therefore, as 15.98 < 26.30, we do not reject H_0.

Conclusion: there is no reason to assume that the *service time in a treatment room when the patient receives a laboratory blood test,* is poorly fitted by the gamma(4.86, 34.89)-distribution.

(III) Time patients spend inside a treatment room (or hallway bed) during the night (between 23h15 and 07h30)

Step 1: Hypothesize families of distribution

In Table A7, we provide a summary of the data of our measurement.

Descriptive statistics		Kurtosis	-0.46
Mean	155.82	Skewness	0.43
Standard Error	9.68	Range	291
Median	151	Minimum	44
Mode	58	Maximum	335
Standard Deviation	72.45	Sum	8726
Sample Variance	5249.57	Count	56

Table A7: Data summary of the time patients spend inside a treatment room (or hallway bed) between 23h15 and 07h30.

Table A7 shows that the skewness is > 0, so the distribution is skewed to the right. Further, the coefficient of variation ($CV=\sigma/\mu$) ≈ 0.46, so the underlying PDF of these data could be a gamma or weibull with an $\alpha > 1$. Also in here, we hypothesis that the underlying distribution is a gamma distribution.

<u>*Step 2: Parameter estimation*</u>

Using the same method described in the paragraph above, we determine the parameters *alpha* (α) and *beta* (β): **α = 4.63**, and **β = 33.69**.

<u>*Step 3: Checking fit between perceived PDF and actual data*</u>

Again, we test a perceived gamma distribution, so we use the Pearson Chi-Square test as we described earlier. We use k=7, $p_j = 1/7 = 0.143$ (for j = 1, …, 7), and test H_0:p_1=p_2=…=p_7 (with α=0.05). We provide an overview of all values in Table A8.

Bin	Start	End	np_j	N_j	$(N_j - np_j)^2/np_j$
1	0.0	82.81	8	12	2.00
2	82.81	108.97	8	3	3.13
3	108.97	132.62	8	4	2.00
4	132.62	157.60	8	4	2.00
5	157.60	187.66	8	7	0.13
6	187.66	232.05	8	8	0.00
7	232.05	∞	8	6	0.50
				Value Chi-Square	9.75

Table A8: Overview of Chi-Square test results.

From the Chi-Square table of critical points we derive that the critical value is 12.59 (df=6). Therefore, as 9.75 < 12.59, we do not reject H_0.

<u>Conclusion:</u> there is no reason to assume that the *time patients spend inside a treatment room (or hallway bed) during the night (between 23h15 and 07h30)* is poorly fitted by the gamma(4.63, 33.69)-distribution.

(IV) Duration indirect waiting times

<u>*Step 1: Hypothesize families of distribution*</u>

Based on the histogram of the data, we expect that an exponential distribution fits the data well if we subtract 2 minutes of each observation. After subtracting 2 minutes of each observation, the summary statistics of the data is as given in Table A9.

Descriptive statistics		Kurtosis	5.08
Mean	9.96	Skewness	2.00
Standard Error	1.19	Range	58
Median	7	Minimum	0
Mode	1	Maximum	58
Standard Deviation	10.68	Sum	797
Sample Variance	114.11	Count	80

Table A9: Data summary of duration indirect waiting time.

Table A9 shows that the skewness is > 0, so the distribution is skewed to the right. Further, the coefficient of variation ($CV=\sigma/\mu$) ≈ 1.07, so the underlying PDF of these data could be an exponential distribution (as the CV ≈ 1). Therefore, we hypothesis that the underlying PDF is an exponential distribution.

Step 2: Parameter estimation

The parameter of the exponential distribution is the *beta* (β), which holds the value of the mean of the sample. From Table A9 we know that the mean, so **β =9.96**.

Step 3: Checking fit between perceived PDF and actual data

To check the fit between the exponential distribution and the actual data (X_1, …, X_n), we can use the Pearson Chi-square test in the same way we described above. We take k=9, with $p_j = 1/9 = 0.111$ for j=1,..,9, and test H_0:$p_1=p_2=\ldots=p_9$ (with α=0.05). Further, we need to rewrite the exponential distribution function to find the inverse function:

$$F(x) = 1 - e^{-x/\beta}$$

$$e^{-\frac{x}{\beta}} = 1 - F(x)$$

$$-\frac{x}{\beta} = Ln(1 - F(x))$$

$$x = -\beta * Ln(1 - F(x)),$$

and use Excel to calculate all values (see Table A10). From the Chi-Square table of critical points we derive that the critical value is 15.51 (df=8). Therefore, as 12.10 < 15.51, we do not reject H_0.

Bin	Start	End	np_j	N_j	$(N_j - np_j)^2/np_j$
1	0.0	1.17	8.89	15	4.20
2	1.17	2.50	8.89	6	0.94
3	2.50	4.04	8.89	8	0.09
4	4.04	5.86	8.89	4	2.69
5	5.86	8.08	8.89	13	1.90
6	8.08	10.94	8.89	8	0.09
7	10.94	14.98	8.89	7	0.40
8	14.98	21.98	8.89	5	1.70
9	21.98	∞	8.89	8	0.38
				Value Chi-Square	12.10

Table A10: Overview of Chi-Square test results.

Conclusion: there is no reason to assume that the *time patients wait to be taken indirectly* is poorly fitted by an exponential distribution with mean 9.96. However, as we subtracted 2 minutes of each observation, our PDF to simulate the ´indirect´ waiting time is: **exponential(9.96)+2**.

(V) Service time triage, when blood is taken by the triage nurse

Step 1: Hypothesize families of distribution

In Table A11, we provide a summary of the data of our measurement.

Descriptive statistics		Kurtosis	-0.13376
Mean	8.071429	Skewness	0.461325
Standard Error	1.285867	Range	17
Median	7,5	Minimum	1
Mode	10	Maximum	18
Standard Deviation	4.811273	Sum	113
Sample Variance	23.14835	Count	14

Table A11: Data summary of service time triage, when blood is taken.

Table A11 shows that the skewness is > 0, so the distribution is skewed to the right. Further, the coefficient of variation ($CV = \sigma/\mu$) ≈ 0.60, so the underlying PDF of these data could be a gamma or weibull with an $\alpha > 1$ (as the $CV < 1$). Therefore, we hypothesis that the underlying PDF is a gamma distribution.

Step 2: Parameter estimation

We use the method described above, and determine the parameters of the gamma distribution as: **α = 2.81**, and **β = 2.87**.

Step 3: Checking fit between perceived PDF and actual data

Again we test a perceived gamma distribution, so we use the Pearson Chi-square test as we described earlier. We use k=4, $p_j = 1/4 = 0.25$ (for j = 1, …, 4), and test H_o:p1=p2=…=p4 (with α=0.05). In Table A12, we provide an overview of all values.

Bin	Start	End	np_j	N_j	$(N_j - np_j)^2/np_j$
1	0.0	4.53	3.5	3	0.07
2	4.53	7.14	3.5	4	0.07
3	7.14	10.60	3.5	4	0.07
4	10.60	∞	3.5	3	0.07
				Value Chi-Square	0.29

Table A12: Overview of Chi-Square test results.

From the Chi-Square table of critical points we derive that the critical value is 7.82 (df=3). Therefore, as 0.29 < 7.82, we do not reject H_0.

Conclusion: there is no reason to assume that the *service time of triage when blood is taken by the triage nurse* is poorly fitted by the gamma(2.81, 2.87)-distribution.

(VI) Service time triage, when NO blood is taken by the triage nurse

Step 1 Hypothesize families of distribution

In Table A13, we provide a summary of the data of our measurement.

Descriptive statistics		Kurtosis	2.67
Mean	5.66	Skewness	1.34
Standard Error	0.17	Range	18
Median	5	Minimum	1
Mode	5	Maximum	19
Standard Deviation	2.90	Sum	1708
Sample Variance	8.43	Count	302

Table A13: Data summary of triage service times, when NO blood is taken.

Table A13 shows that the skewness is > 0, so the distribution is skewed to the right. Further, the coefficient of variation ($CV = \sigma/\mu$) ≈ 0.60, so the underlying PDF of these data could be a gamma or weibull with an $\alpha > 1$. We hypothesis that the underlying distribution is best fitted by a gamma distribution.

Step 2: Parameter estimation

Using the same method described in the paragraph above, we determine the parameters *alpha* (α) and *beta* (β): **α = 3.79**, and **β = 1.49.**

Step 3: Checking fit between perceived PDF and actual data

We test a perceived gamma distribution, so we use the Pearson Chi-Square test as we described earlier. We use k=5, $p_j = 1/5 = 0.20$ (for j = 1, …, 5), and test H_o:p1=p2=…=p5 (with α=0.05). We provide an overview of all values in Table A14.

Bin	Start	End	np_j	N_j	$(N_j - np_j)^2/np_j$
1	0.0	3.19	60.40	58	0.10
2	3.19	4.50	60.40	57	0.19
3	4.50	5.90	60.40	70	1.53
4	5.90	7.85	60.40	58	0.10
5	7.85	∞	60.40	59	0.03
				Value Chi-Square	1.94

Table A14: Overview of Chi-Square test results

From the Chi-Square table of critical points we derive that the critical value is 9.48 (df=4). Therefore, as 1.94 < 9.48, we do not reject H_0.

Conclusion: there is no reason that the *service time of triage when blood is taken by the triage nurse* is poorly fitted by the gamma(2.81, 2.86)-distribution.

(VII) Time waiting room 1

We observed that patients can be waiting in the waiting room for the triage room, while the triage room is empty. At these moments, the triage nurse is not at the triage room, causing a delay in the throughput of a patient. In order to prevent our model of being to 'positive' (when the triage room is empty, the patient is placed immediately inside), we include a minimum waiting time these patients spend in the waiting room.

To obtain the needed data to determine a distribution for the minimum time in waiting room 1, we determine the duration of patients waiting in the waiting room while the triage room was empty. In Table A15 we provide a summary of these data. In here, we excluded two outliers with values more than 35 minutes. We excluded those times as it is highly unlikely that a patient needs to wait above 35 minutes for triage when the triage room is empty. The triage nurse is assigned to the triage room and has no additional tasks. And although we observed that the triage nurse was occasionally not directly present to triage a patient, for example when the triage nurse escorted a patient to a treatment room and quickly helped his/her colleague in the treatment room with an ECG, we estimate that this took maximally 10 minutes. However, as we did not measure the time the triage nurse was *elsewhere*, we decide to except an interval twice as long, being 20 minutes. But when we look at the frequency that patients waited a specific number of minutes for triage, while the triage room was not in use (see Figure A1), we see that one patient waited 21 minutes. We decide to include the waiting time of 21 minutes, and exclude only the two outliers with values more than 35 minutes.

Step 1: Hypothesize families of distribution

Descriptive statistics		Kurtosis	3.59
Mean	3.78	Skewness	1.72
Standard Error	0.22	Range	21
Median	3	Minimum	0
Mode	2	Maximum	21
Standard Deviation	3.61	Sum	1002
Sample Variance	13.02	Count	265

Table A15: Data summary of triage service times, when blood is taken.

Table A15 shows that the skewness is > 0, so the distribution is skewed to the right. Further, the coefficient of variation ($CV=\sigma/\mu$) ≈ 0.95, so the underlying PDF of these data could be an exponential distribution. However, considering the shape of the distribution (see Figure A1) it is more likely that the distribution follows a gamma distribution with an $\alpha > 1$. Therefore, we hypothesis that the underlying distribution is a gamma distribution.

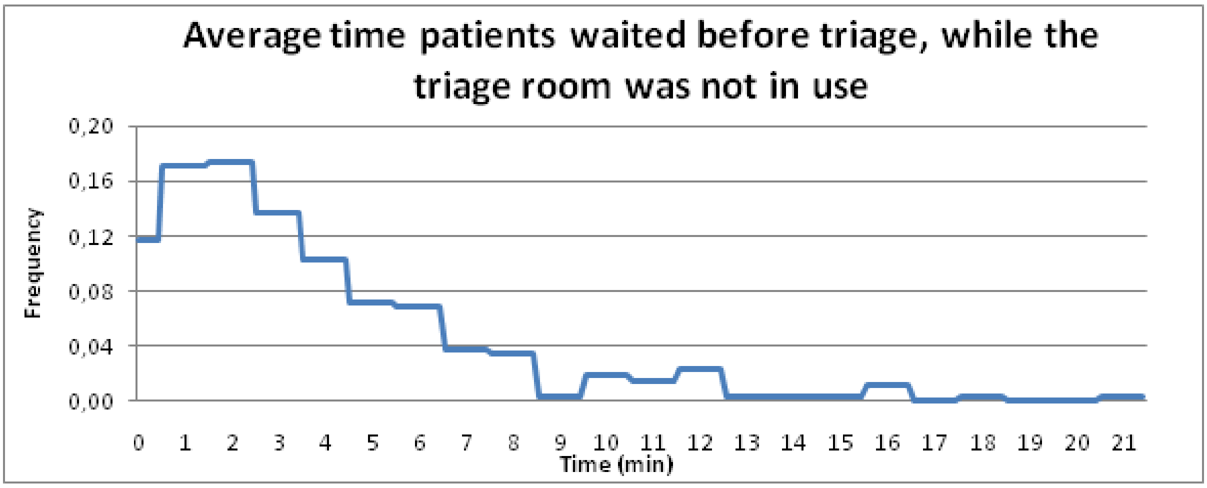


Figure A1: Time patients waited in front of the triage room, while the room was not in use (Measurements, 2011; n=265).

Step 2: Parameter estimation

Using the same method described in the paragraph above, we determine the parameters *alpha* (α) and *beta* (β): **α = 1.17**, and **β = 3.28.**

Step 3: Checking fit between perceived PDF and actual data

We use k=7, p_j = 1/7 = 0.143 (for j = 1, …, 7), and test H_0:p_1=p_2=…=p_7 (with α=0.05). In Table A16, we provide an overview of all values.

Bin	Start	End	np_j	N_j	$(N_j - np_j)^2/np_j$
1	0.0	0.74	37.86	31	1.24
2	0.74	1.47	37.86	45	1.35
3	1.47	2.32	37.86	46	1.75
4	2.32	3.38	37.86	36	0.09
5	3.38	4.84	37.86	27	3.11
6	4.84	7.27	37.86	47	2.21
7	7.27	∞	37.86	33	0.62
				Value Chi-Square	10.38

Table A16: Overview of Chi-Square test results.

From the Chi-Square table of critical points we derive that the critical value is 12.59 (df=6). Therefore, as 10.38 < 12.59, we do not reject H_0.

Conclusion: there is no reason to assume that the *average time patients wait in front of the triage room, when the room was not used* is poorly fitted by the gamma(1.17, 3.28)-distribution.

(VIII) Time waiting room 2

We observed that patients are often not directly placed inside a treatment after triage, even when a room is available. Caused by delaying factors, other than 'room availability' (e.g. the nurses working on the ED area where the patient needs to be treated are all busy with activities for other patients), we need to simulate that patients wait a specific duration after triage in the waiting room. This is achieved by providing each patients after triage in the triage room, with a minimum time they need to stay in the waiting room before they can be placed in a treatment room.

To derive a probability function, we use the waiting times of patients waiting in the waiting room after being triaged, while not all treatment rooms are occupied (with 14 medium/ high care rooms available). We provide the descriptive data of this subsample of patients waiting in the waiting room after triage in Table A17.

Step 1: Hypothesize families of distribution

Descriptive statistics		Kurtosis	8.34
Mean	7.98	Skewness	2.63
Standard Error	1.07	Range	65
Median	5	Minimum	0
Mode	0	Maximum	65
Standard Deviation	11.77	Sum	973
Sample Variance	138.47	Count	122

Table A17: Data summary of minimum waiting time after triage by the triage nurse.

Table A17 shows that the skewness is > 0, so the distribution is skewed to the right. Further, the coefficient of variation (CV=σ/μ) ≈ 1.48, so the underlying PDF of these data could be a gamma or weibull with an $\alpha < 1$. Therefore, we hypothesis that the underlying distribution is best fitted by a gamma distribution with an $\alpha < 1$.

Step 2: Parameter estimation

Using the same method described in the paragraph above, we determine the parameters *alpha* (α) and *beta* (β): **α = 0.46**, and **β = 17.36**.

Step 3: Checking fit between perceived PDF and actual data

We use k=5, $p_j = 1/5 = 0.2$ (for j = 1, …, 5), and test H_o:p1=p2=…=p5 (with α=0.05). In Table A18 we provide an overview of all values.

Bin	Start	End	np_j	N_j	$(N_j - np_j)^2/np_j$
1	0.0	0.41	24.40	32	2.37
2	0.41	1.96	24.40	15	3.62
3	1.96	5.37	24.40	29	0.87
4	5.37	13.04	24.40	23	0.08
5	13.04	∞	24.40	23	0.08
				Value Chi-Square	7.02

Table A18: Overview of Chi-Square test results.

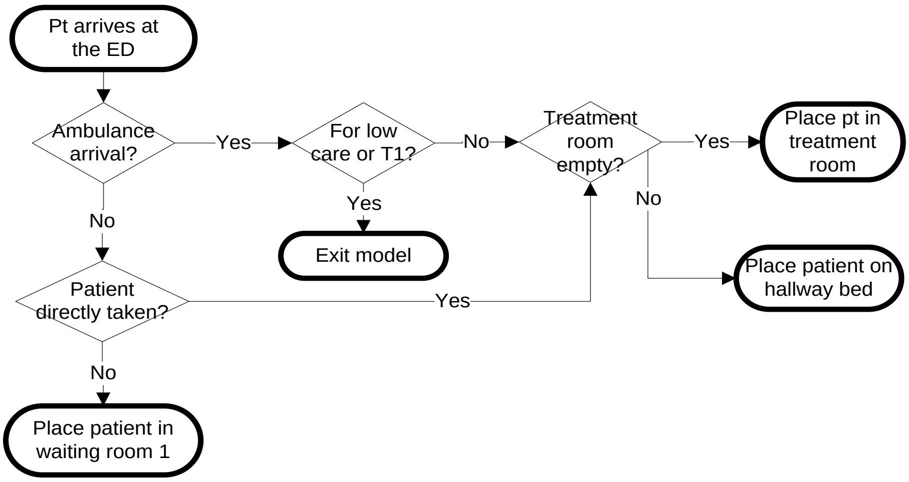
From the Chi-Square table of critical points we derive that the critical value is 7.02 (df=4). Therefore, as 7.02 < 9.49, we do not reject H_0.

Conclusion: there is no reason to assume that the *minimum waiting time patients wait after triage* is poorly fitted by the gamma(0.46, 17.36)-distribution.

Appendix D Flowcharts

This appendix contains the three flowcharts we used to validate and build our simulation model.

Figure A2: New patient arrival flowchart



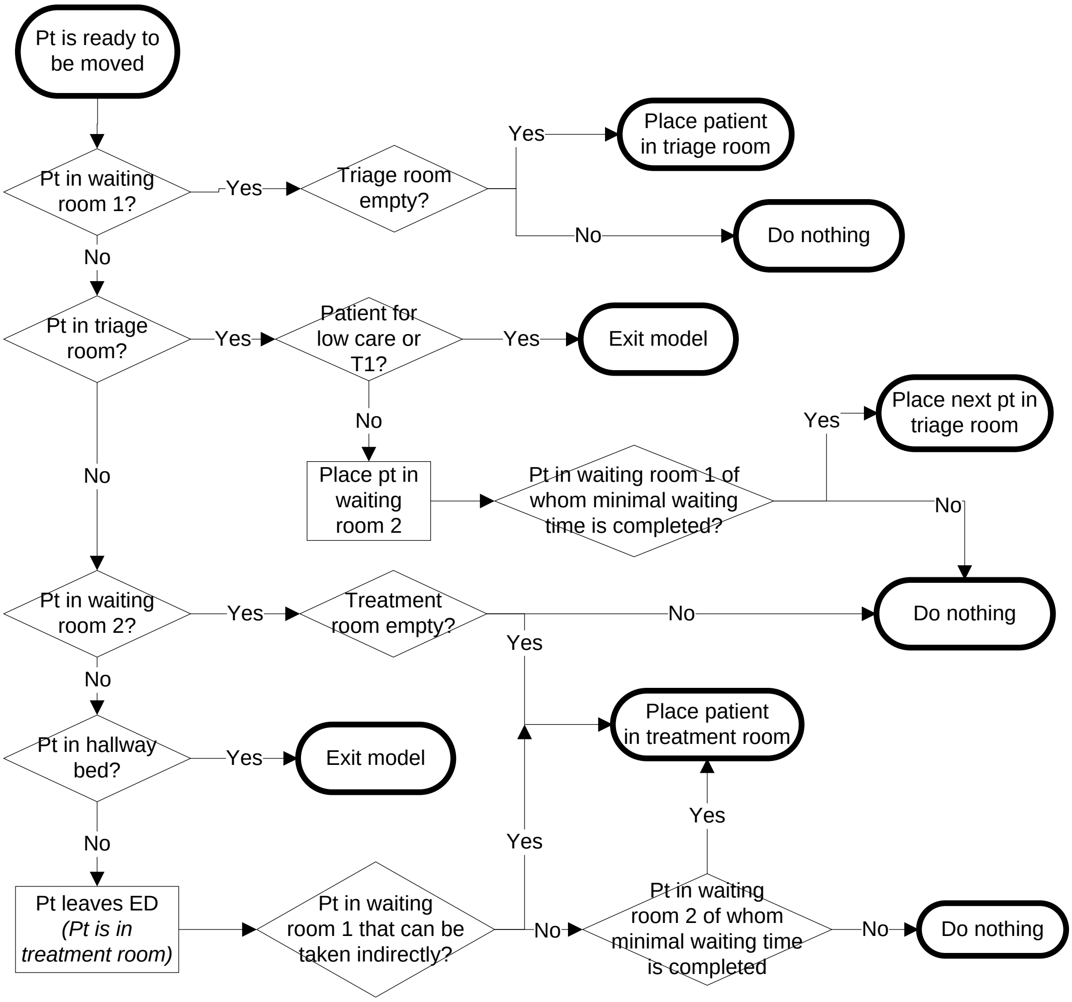


Figure A3: Patient is 'completed' at station and is ready to be moved to next station

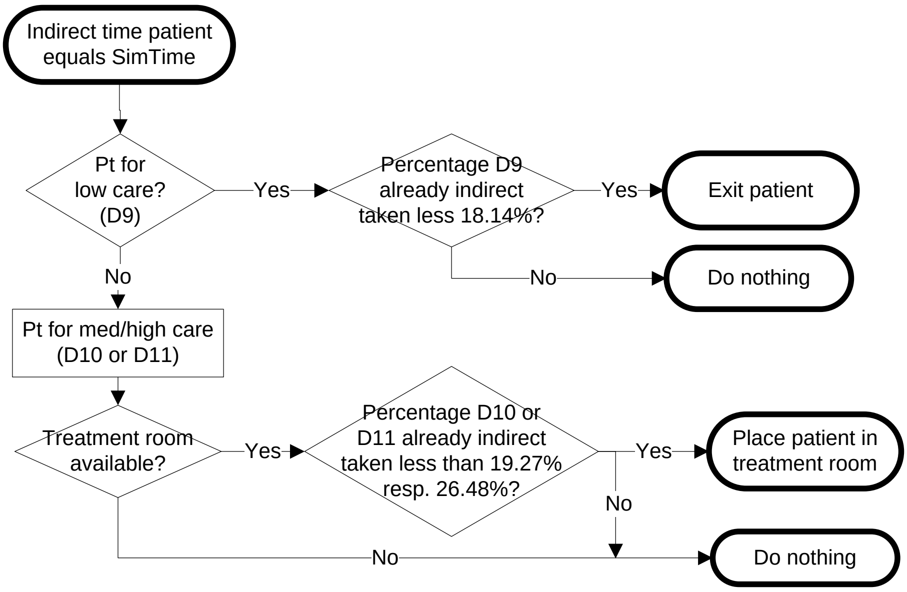


Figure A4: Flowchart to regulate the patient paths of patients indirectly taken

Appendix E Number of replications

In this appendix, we determine the number of replications (number of days) that we need to run our model to obtain enough output data to derive reliable conclusions upon the *waiting time to triage* and the *patient LOS of patients receiving a blood tests form the triage nurse* during different model configurations. To determine the number of replications needed, we use the data of 81 days, from which we exclude the first day as warm up, and use the following formulae to calculate the number of replications (n^*) needed (Law, 2007):

$$n^*(\beta) = \min\left\{ i \geq n : t_{\left(i-1,1-\frac{1}{2}\alpha\right)}\sqrt{S_n^2/i} \leq \beta \right\},$$

with $S_n^2 = \frac{\sum_{j=1}^{n}(X_j - \bar{X})^2}{n-1}$, and

β the maximum error allowed.

From the formulae can be derived that the number of replications needed depends on the maximum error allowed. To determine this value, a commonly used method is a 5% or 10% *relative* error (Law, 2007). Knowing that the average waiting time to triage is 7 minutes and 17 seconds (Measurements, 2011), a reasonable maximum error allowed would be between 22 and 43 seconds. Therefore, we decide that we want to determine the expected increase in *waiting time to triage* with a maximum error of 30 seconds. We also know that the average patient LOS of patients receiving a blood test is 182 minutes (Measurements, 2011), yielding that a reasonable maximum error would be between 9 and 18 minutes. However, we feel this error is too large, and decide to allow a maximum error of only 3 minutes.

Further, we want to test our intervention of 'the triage nurse starts blood tests´ in three different scenario's. The scenario´s and the number of replications needed per scenario are given in Table A19.

	Configuration			**Number of replications (α=0.05)**	
Scenario	Input arrival rate	Min. waiting time to placement in treatment room +34% ?	Blood started by triage nurse?	Waiting time to triage	Patient length of stay (D10)
1	2011	No	No	75	44
			Yes	51	289
2	2010	No	No	68	140
			Yes	413	235
3	2010	Yes	No	79	153
			Yes	382	330

Table A19: Number of replications needed.

The highest number of replications found is 413 days. Therefore, including that the first day is always deleted as warm-up, when testing each of the configurations, we need to run our model for 414 days.