THE QUANTITATIVE AND QUALITATIVE DIFFERENCES BETWEEN THE LOCATIONS OF AN ACUTE MEDICAL UNIT

A case study at ZGT Almelo

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MASTER THESIS

THE QUANTITATIVE AND QUALITATIVE DIFFERENCES BETWEEN THE LOCATIONS OF AN ACUTE MEDICAL UNIT

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Management summary

Background

One of the priorities of Ziekenhuisgroep Twente (ZGT) is to optimize patient logistics. ZGT increasingly seeks to coordinate the presented patient flows as efficient as possible. ZGT Almelo wants to stabilize the process of acute admissions, reduce the number of patients placed in an inappropriate ward, shorten the length of hospital stay, reduce congestion and throughput time at the emergency departments, reduce the number of admission stops and effective use of medical staff.

ZGT is currently considering establishing an Acute Medical Unit (AMU) in order to achieve the above goals. Due to financial matters, ZGT Almelo has pronounced a proposed decision to establish an AMU, in principle on the current location of the ambulatory on the 5th floor. ZGT would like to get insight in the differences in both quantitative as qualitative measures when the AMU is located near the emergency department, the current location of the outpatient department rheumatology/ophthalmology, compared to an AMU located on the 5th floor at the current ambulatory.

Approach

To identify the differences in the locations of an AMU, we simulated the acute admission process of an AMU. For this purpose, we used Discrete Event Simulation (DES) in order to get insight in the quantitative criterion. We used the total transportation costs as a quantitative criterion. We performed an Analytic Hierarchy Process (AHP) analysis in order to compare the qualitative criteria. We have two interventions in which we compare the differences in the total transportation times, namely an AMU located on the 5th floor and an AMU located on the ground floor near the ED. We defined three scenarios for measuring the total transportation times. The first scenario is based on the current arrivals at the AMU, the second on the current arrivals including the specialty lung diseases, and the third is based on the current arrivals including the specialty lung diseases and with a grow of 10%.

The qualitative criteria used in this study are: communication between staff members, early consultant review, flexibility with regard to possible expansion, patient flow and exchange of nurses between the ED and AMU. The AHP analysis is conducted among different stakeholders.

Results

Table 1 shows the results of the experiments we performed in the simulation model, by means of the yearly costs for the total transportation times. The total costs increase when the number of arrivals are increased. We see that the total costs for each scenario on the 5th floor are significantly higher than the intervention in which the AMU is located on the ground floor.

Table 1 - Costs summary for the total transportation times for different scenarios

	AMU on the 5th floor			*AMU on the ground floor*		
	Current arrivals	Current arrivals including lung	Current arrivals including lung plus 10% growth	Current arrivals	Current arrivals including lung	Current arrivals including lung plus 10% growth
FTE	0.71	0.88	0.95	0.19	0.24	0.25
Costs in Euros (€)	23,931	29,745	32,224	6,133	7,819	8,182

The results of the AHP analysis are shown in Table 2. Criteria 3 and 4, respectively the 'flexibility with regard to possible expansion' and the 'patient flow' have the highest priority vectors. Criterion 5, 'exchange of nurses between the ED and the AMU' has a relative low value. The resulted final priorities for both interventions are calculated. As can be seen, the intervention in which the AMU is located near the ED on the ground floor has a better score on each criterion.

Table 2 - Final priorities of the AHP analysis

	C_1 (0.17)	C_2 *(0.17)*	C_3 *(0.29)*	C_4 *(0.29)*	C_5*(0.07)*	**Final Priority**
AMU on 5th floor	0.125	0.25	0.1	0.25	0.125	0.18
AMU on ground floor	0.875	0.75	0.9	0.75	0.875	0.82

Conclusion and recommendations

We conclude that an AMU located on the ground floor offers both quantitative as qualitative benefits. The total transportation costs are significantly lower in this case. The difference in costs between the two interventions in scenario 1, 2 and 3 are respectively €18,766, €23,056 and €25,365. According to the AHP analysis we performed, the best intervention is the one in which the AMU is located near the ED on the ground floor with a score of 82%. This intervention has a better score on each criterion compared to the intervention in which the AMU is located on the 5th floor.

The costs of realizing an AMU should be weighed against both the quantitative as the qualitative advantages it provides if the AMU is located on the ground floor. We recommend on doing further research in possibilities for flexible nurse staffing between the ED and the AMU in order to determine the appropriate nurse staffing levels and to make efficient use of the nurses at both the ED and the AMU.

Management samenvatting

Achtergrond

Eén van de prioriteiten van de Ziekenhuisgroep Twente (ZGT) is het optimaliseren van de patiënten logistiek. In toenemende mate wordt gestreefd naar het zo efficiënt mogelijk coördineren van de aangeboden patiëntenstroom. ZGT Almelo wil het proces ten aanzien van de acute opnames stabiliseren. Daarnaast wil het ZGT het aantal patiënten op een 'ongewenste' afdeling verminderen, verkorten van de ligduur, reduceren van de doorlooptijd op de spoedeisende hulp (SEH), reduceren van het aantal opname stops en effectief gebruik maken van medisch personeel.

ZGT Almelo beraadt zich momenteel over het instellen van een Acute Opname Afdeling (AOA) om bovenstaande doelen te bereiken. Ten gevolgen van financiële zaken heeft het ZGT een voorgenomen besluit uitgesproken om een AOA te gaan realiseren, in eerste instantie op de huidige locatie van het ambulatorium op de 5e verdieping. ZGT wil graag inzicht verkrijgen in zowel de kwantitatieve als kwalitatieve verschillen indien de AOA in de buurt van de SEH op de begane grond wordt gerealiseerd, vergeleken met de situatie waarin de AOA op de 5e verdieping, op het huidige ambulatorium wordt gerealiseerd.

Methode

Om inzicht te verkrijgen in de kwantitatieve verschillen ten gevolgen van de locatie van de AOA, hebben we het proces ten aanzien van de acute opnames gesimuleerd aan de hand van een Discrete Event Simulation (DES). We hebben een Analytic Hierarchy Process (AHP) analyse uitgevoerd om de kwalitatieve verschillen te kunnen vergelijken. De totale transportkosten zijn gebruikt als kwantitatieve maat. We hebben twee interventies waarin we kijken naar de verschillen op zowel kwantitatief als kwalitatief gebied, namelijk een AOA gesitueerd op de 5e verdieping op het huidige ambulatorium en een AOA gesitueerd in de buurt van de SEH op de begane grond. We hebben 3 scenario's gedefinieerd voor het meten van de totale transporttijden. Het eerste scenario is gebaseerd op de huidige aankomsten, het tweede scenario is gebaseerd op de huidige aankomsten inclusief het specialisme 'longziekten', en het derde scenario is gebaseerd op het 2e scenario met een groei van 10% ten opzichte van het aantal aankomsten.

De kwalitatieve criteria die we in deze studie hebben gebruikt zijn: de communicatie tussen medisch personeel van de SEH en de AOA, tijdig visite lopen van artsen, flexibiliteit ten aanzien van de mogelijke uitbreiding, patient flow en de uitwisseling van verpleegkundigen tussen de SEH en de AOA. De AHP is uitgevoerd onder verschillende betrokkenen.

Resultaten

In Tabel 3 zijn de resultaten weergegeven van de verschillende experimenten die we hebben uitgevoerd, uitgedrukt in jaarlijkse kosten van de totale transport tijden. De totale kosten nemen toe indien het aantal aankomsten wordt verhoogd. We zien dat de totale kosten voor elk scenario op de 5e verdieping aanzienlijk hoger zijn dan de interventie waarin de AOA is gesitueerd op de begane grond.

Tabel 3 - Overzicht van de totale transport kosten voor de verschillende scenario's

	AOA op de 5e verdieping			*AOA op de begane grond*		
	Huidige aankomsten	Huidige aankomsten inclusief longziekten	Huidige aankomsten inclusief longziekten plus 10% groei	Huidige aankomsten	Huidige aankomsten inclusief longziekten	Huidige aankomsten inclusief longziekten plus 10% groei
FTE	0,71	0,88	0,95	0,19	0,24	0,25
Kosten in euro's (€)	23.931	29.745	32.224	6.133	7.819	8.182

De resultaten van de AHP analyse zijn weergegeven in Tabel 4. Criteria 3 en 4, respectievelijk de 'flexibiliteit ten aanzien van de mogelijke uitbreiding' en de 'patient flow' hebben de hoogste 'priority values'. Criterium 5, de 'uitwisseling van verpleegkundigen tussen de SEH en de AOA' heeft een relatief lage prioriteit. De uiteindelijke prioriteiten zijn weergegeven in onderstaande tabel. We zien dat de interventie waarin de AOA is gesitueerd op de begane grond een betere score heeft op ieder criterium.

Tabel 4 - Prioriteiten van de AHP analyse

	C_1 (0,17)	C_2 (0,17)	C_3 (0,29)	C_4 (0,29)	C_5(0.07)	**Final Priority**
AOA op de 5e verdieping	0,125	0,25	0,1	0,25	0,125	0,18
AOA op de begane grond	0,875	0,75	0,9	0,75	0,875	0,82

Conclusie en aanbevelingen

We concluderen dat een AOA gesitueerd op de begane grond voordelen biedt op zowel kwantitatief als kwalitatief gebied. De totale transport kosten zijn aanzienlijk lager in deze situatie. Het verschil in kosten tussen de twee interventies in scenario 1, 2 en 3 is respectievelijk €18.766, €23.056 en

€25.365. Uit de resultaten van de AHP analyse blijkt dat de situatie waarin de AOA is gesitueerd op de begane grond de beste interventie is met een score van 82%. De kosten van het realiseren van een AOA zullen moeten worden afgewogen tegen zowel de kwantitatieve als de kwalitatieve voordelen die het biedt indien de AOA op de begane grond is gesitueerd. Tenslotte raden we aan om verder onderzoek te doen naar de mogelijkheden van het flexibel roosteren van verpleegkundigen van de SEH en de AOA om op deze manier efficiënt gebruik te maken van de verpleegkundigen op de SEH en AOA.

Preface

This report is the result of my graduation project in Ziekenhuisgroep Twente (ZGT). This thesis completes my Master program Industrial Engineering & Management at the University of Twente, specialization Health Care Technology and Management. During my time in ZGT, I got involved in the environment of hospitals, especially acute admissions, which has become a topic of my interest.

I would like to thank Annemarie Visschedijk for her guidance at the ambulatory and making sure I was always in contact with the right people. Also great thanks to Jasper Quik for meeting with me every couple of weeks and the valuable input in my research.

I would also like to thank my supervisors from the University of Twente. I would like to thank Erwin Hans for his support and enthusiasm and the useful feedback on my thesis. I also want to thank Derya Demirtas for her valuable feedback.

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Karlijn Alferink

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1. Introduction

In the last decade, many hospitals have seen a substantial rise in emergency admissions in combination with a reduction in number of hospital beds and an increase in bed occupancy rates (Capewell, 1996). This has often resulted in admitted patients being distributed to other wards than the specific specialty and receiving inadequate care. The lack of bed capacity has led to overcrowding in hospitals, congestion in emergency departments, unnecessarily long length of stay and greater risks to patients of medical errors and complications (Scott, Vaughan, & Bell, 2009). One solution that is growing in popularity to face these problems is the establishment of an acute medical unit (AMU).

Ziekenhuisgroep Twente (ZGT) also encounters some problems due to the emergency admissions. As a result, throughput times at the emergency department increase, leading to congestion and unsuitable ward placements. Emergency admissions are disrupting the processes on the wards and cause high workload on the wards in case of emergency admissions. ZGT Almelo has pronounced a proposed decision to establish an AMU.

This chapter provides background information of the ZGT and describes the research objective and approach of this study. Section 1.1 outlines the organization and elaborates on the Acute Medical Unit. Section 1.2 states the problem description and Section 1.3 describes the research objective and approach.

1.1 Research context

Section 1.1.1 gives a brief description of the organization and Section 1.1.2 elaborates on the Acute Medical Unit.

1.1.1 Ziekenhuisgroep Twente

Ziekenhuisgroep Twente (ZGT) is a merged hospital, and consists of two hospitals, ZGT Almelo and ZGT Hengelo. ZGT was formed in 1998 after the merger of Twenteborg Ziekenhuis in Almelo and Streekziekenhuis Midden-Twente in Hengelo. ZGT is a general hospital with over 3500 employees and a service area of more than 300,000 inhabitants.

In 2015, 22,707 acute patients were admitted at the emergency department. Besides, ZGT had 25,000 day-care admissions of which 2-3% were acute. ZGT Almelo focuses on acute care. ZGT Almelo has multiple acute entrances where acute patients are seen. This concerns the emergency department (ED), the coronary care unit (CCU) / the emergency cardiac care (ECC), the delivery-rooms, the brain care unit, intensive care (IC) and the initial care for acutely ill children at the paediatric department. The acute care at the emergency department at location Hengelo is minimized. The acute entrances in Hengelo concern the ED, the CCU/ECC and the paediatric department for acutely ill children.

ZGT Almelo has an ambulatory ward. Patients who are treated at the observation ward are urgently admitted. Patients from which is not certain whether they need hospitalization are also transferred to this ward. The aim is that patients stay no longer than 24 hours at the observation ward. Reasons for an admission at the ambulatory could be: diagnosing, preparing for surgery or a brief observation. After admission at the ambulatory, the patient is transferred to another medical ward in the hospital for further diagnosis and/or treatment, or is sent home.

ZGT wants to create a better quality of care for acute admitted patients, a more efficient planning by dividing the elective and acute admissions, less variability of acute admission arrivals at medical wards, a reduction in average length of hospital stay, and a less variable workload for nurses as well as for medical specialists by implementing an AMU.

1.1.2 Acute Medical Unit

An AMU is a clinical admission ward where patients are acutely admitted from the emergency department or outpatient departments. According to Bell, Skene and Jones (2008), an AMU is defined as: designated hospital wards specifically staffed and equipped to receive medical inpatient presenting with acute medical illness from emergency departments and/or the community for expedited multidisciplinary and medical specialist assessment, care and treatment for up to a designated period (typically between 24 and 72 h) prior to discharge or transfer to medical wards. These units are supervised by feature multidisciplinary teams that comprehensively assess and manage both medical illness and functional disability (Bell, Skene, & Jones, 2008). In short, an AMU is a clinical admission ward where the unscheduled patients with acute medical problems can be admitted for a maximum of 24, 48 or 72 hours. With an AMU, the acute and elective patient flows are separated. In general, an AMU admission policy grants entry to any patient with an acute medical condition, referred from the emergency department or directly from primary care practitioners.

Figure 1 represents the patient flow for acute admitted patients via an AMU.

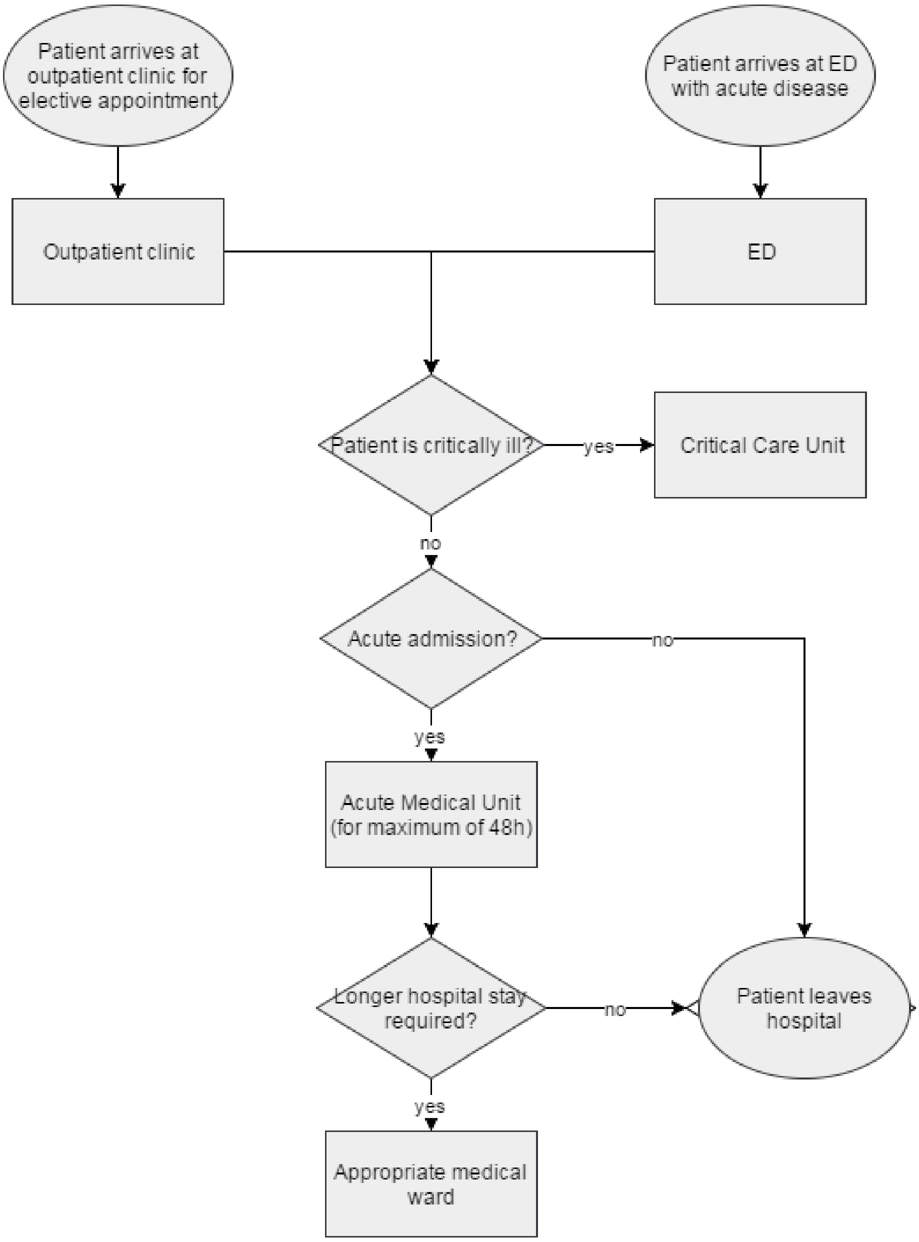


Figure 1 - Traditional model of an AMU

1.2 Problem description

One of the priorities of ZGT is to optimize patient logistics. ZGT increasingly seeks to coordinate the presented patient flows as efficient as possible. ZGT Almelo wants to stabilize the process of acute admissions, reduce the number of patients placed at an inappropriate ward, shorten the length of hospital stay, reduce congestion and throughput time at the emergency departments, reduce the number of admission stops and effective use of medical staff.

Research within ZGT Almelo shows that an AMU could have positive effects on the coefficient of variation in acute admission arrivals to medical wards. It is also expected that an AMU has positive effects on the percentage of misplaced patients, the throughput time at the emergency department, the bed occupancy, the in-hospital mortality rate, length of hospital stay and the number of admission stops. Given this positive effects, ZGT wants to establish an AMU. ZGT Almelo wants to determine the most convenient location to implement an AMU.

There exist no clear directives about the location of an AMU. There is no evidence whether geographical location of the acute medical unit is significant. Though it has often been suggested that a position within, or in very close proximity to the emergency department (ED) is very important. Cooke, Higgins and Kidd (2003) argue that an AMU should be in a well-defined area. Ideally this is within the emergency department or directly adjacent to it. An American study has noted that 93% of the acute medical units were located near the emergency department (Cooke, Higgins, & Kidd, 2003). Scott et al. (2009), Cooke et al (2003), and Moloney et al. (2005) stated that the AMU is preferably located near the ED and the diagnostic facilities such as the laboratory and radiology, because the transfer between the units will commonly occur.

Due to financial matters, ZGT Almelo has pronounced a proposed decision to establish an AMU, in principle on the current location of the ambulatory on the 5th floor. ZGT would like to get insight in the differences in both quantitative as qualitative measures when the AMU is located near the emergency department, the current location of the outpatient department rheumatology/ophthalmology on the ground floor, compared to an AMU located on the 5th floor at the current ambulatory.

1.3 Research objective and questions

From the problem description described in section 1.2, section 1.3.1 describes the research objective and section 1.3.2 gives the research approach by several research questions.

1.3.1 Research objective

The objective of this research is to gain insight in both the quantitative and qualitative differences of an AMU situated near to the emergency department, the current location of the outpatient rheumatology/ophthalmology on the ground floor, compared to an AMU situated on the 5th floor at the current ambulatory. This objective especially focuses on the admission process at the AMU. The result of this research contributes to the decision where the AMU should be located. It also contributes to the knowledge on how acute care can be organized in the most efficient way.

1.3.2 Research questions

The research objectives are realized by answering the following research questions corresponding to the following chapters.

Chapter 2: Context analysis

How is the current emergency admission process organized?

In this chapter, a situational analysis of the current performance is performed. The arrival processes are identified and the planning and control of acute patients and resources is described.

Chapter 3: Theoretical framework

What is known in the literature about evidence of effectiveness and efficacy of AMUs, related facility layout problems and flexible nurse staffing?

In this chapter, a literature review is performed in order to find out what is already known in related literature.

Chapter 4: Simulation model

How can we model the acute admission process?

In this chapter, we determined how the current emergency admission process can be modelled. We will identify what changes occur when an Acute Medical Unit will be established and how we can model this. We will verify and validate the model we build.

Chapter 5: Results

What are the results of the executing experiments?

In this chapter, key performance indicators are formulated which are used to measure the performance of the current emergency admission process. Furthermore, the interventions we want to test on the simulation model are determined. We describe how the interventions will be translated into experiments to conduct on the model described in chapter 4. After running these experiments, we will analyse the results.

Chapter 6: Conclusion and recommendations

What is the conclusion of this study and what are the recommendations?

In this chapter we provide an overall conclusion of this study. Furthermore, we come up with some recommendations for emergency admission process at ZGT Almelo.

2 Context Analysis

In this chapter we describe the context of our research, in order to gain insight in the current acute admission processes of Ziekenhuisgroep Twente. The context analysis starts with the care path description in section 2.1. Section 2.2 describes the arrival processes of acute admissions at the Emergency Department and the Acute Medical Unit. Section 2.3 describes the current planning of acute admissions and the planning of resources. In Section 2.5 we draw a conclusion of Chapter 2.

2.1 Care path description

In this section, the care path of acute admitted patients is described and visually represented in Figure 2.

There are different ways in which an acute patient may enter the ED. The first way to enter the ED is by external referral. The patient can be referred by his or her GP or an external specialist. An external referred patient is a patient from which it is known in advance that he or she is coming to the ED. A patient can also be referred by an internal specialist from the outpatient clinic. Another way to enter the ED is by self-referral. In this case, the patient skips the GP and goes directly to the ED.

The first step that is taken at the ED is determining the urgency on the basis of complaints of the patient. This is done by means of a triage. The ED makes use of the NTS (Netherlands Triage System) standard. If a patient is critically ill, the patient will directly be referred to a critical care unit. After the triage, further diagnostic tests are performed if necessary. The waiting time is dependent of the triage/urgency of the patient but also of the availability of resources at the ED and the diagnostic departments. Patients will be transferred to one of the diagnostic departments. The patient will go back to the ED to wait for the results. At the ED, the admission policy will be defined. If the admission policy is known, the patient can leave the ED in three different ways:

1. The patient is admitted to the observation ward for a short observation or another hospital ward for further treatment
2. The patient is admitted to a critical care unit
3. The patient is sent home, with or without a follow-up consultation

The medical specialist decides whether a patient needs to be admitted for medical treatment or further observation. In case the patient is expected to be admitted for a short period of time, the patient will be referred to the ambulatory, if there is a bed available. If there is no bed available, the patient will be transferred to the (appropriate) medical ward. The nurse from the specific department picks up the patient from the ED. The physicians visit their patients at the specific department. At the ambulatory, the appointment is that the physician visits their patients between 8.00 and 12.00 in the morning. In case the patient has to be admitted for a longer period of time, the patient will be transferred to the appropriate medical ward. If there is no bed available at the appropriate ward, the patients will be temporarily transferred to the observation ward or admitted to another preference ward. In case there is a bed available at the appropriate medical ward, the patient will be transferred to the appropriate ward in order to receive adequate care from the right nurses and specialists of the specific specialty. The medical specialist decides if a patient could be discharged, either to another hospital, a care facility or home. Figure 2 gives an overview of the care path of an acute admission.

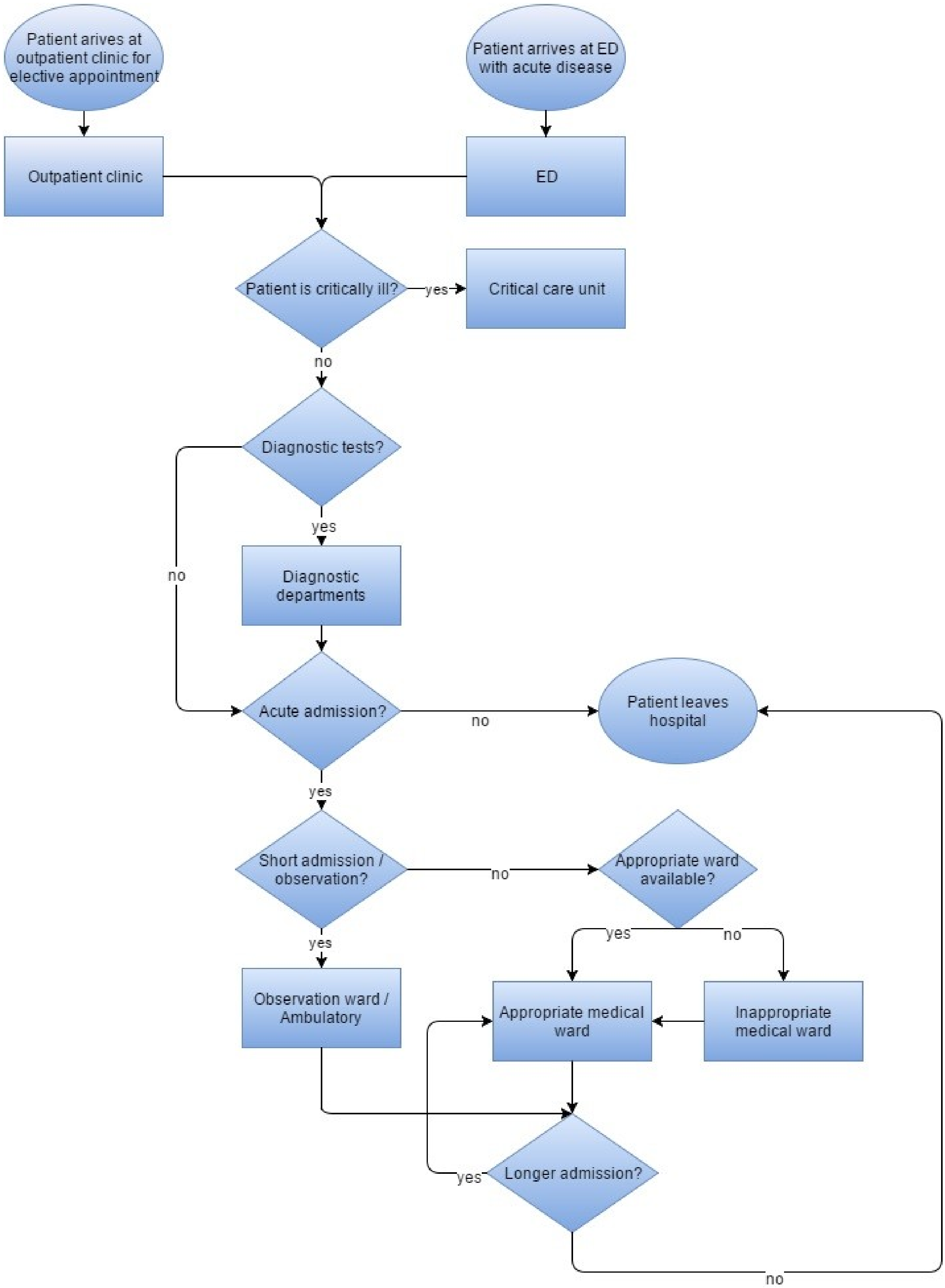


Figure 2 - Current acute admission process

2.2 Planned changes

Acutely admitted patients from the emergency department or outpatient clinic will be transferred to the AMU instead of the ambulatory or another medical ward when establishing an AMU. The current ambulatory will no longer exist. There is a variety of synonyms for AMUs including acute assessment unit (AAU), acute medical assessment unit (AMAU), medical assessment and planning unit (MAPU), acute medical wards (AMW), acute planning units (APU), rapid assessment medical units (RAMU) and early assessment medical units (EMU). In this report we will use the term Acute Medical Unit (AMU).

The AMU will have a bed-capacity of 36 of which 6 with monitor observation. Only the patients who belong to the inclusion criteria will be transferred to the AMU. The specialties that belong to the inclusion criteria are: surgery, anaesthesiology, dermatology, gastro-enterology, internal surgery, throat-, nose- and otology, oral pathology and dental surgery, ophthalmology, plastic surgery, rheumatology and urology. Acutely admitted patients from the other specialties will be transferred to their own specialist departments. Acutely admitted patients will stay at the AMU for a maximum designated period of 48 hours. After this period, patients will be discharged or transferred to a medical ward.

The following care related activities take place at the AMU: admission of the acute patient including the administrative actions, nursing and treating patients, providing information to the patient and his family, coordinating and organizing patient transport and organizing patient transfer to another medical ward, home or another care facility.

The specialists from each specialty come to the AMU to review the patients of its own specialty twice a day. The throughput at the AMU is controlled by an efficient medical coordination through the early review of physicians and the resulting consequences. The various diagnostic departments should be prepared to handle acute patients from the AMU. There two discharge times per day in which patients can be discharged to home, a medical ward or another care facility.

2.3 Arrival processes

In this section, we perform a historical data analysis in order to determine the acute arrival processes at the ED and the AMU. In addition, we determine the underlying statistical distribution of the arrivals by which we can correctly model the arrivals in the simulation model. Since the number of acute admissions is significantly increased in 2015 with respect to 2014, we used data from all full weeks of 2015.

2.3.1 Arrivals at the emergency department

First, we analyse the average number of arrivals for each day at the ED. Figure 3 demonstrates the busy and quiet days. Monday and Friday can be identified as the busiest days. Sunday can be identified as a relatively quiet day.

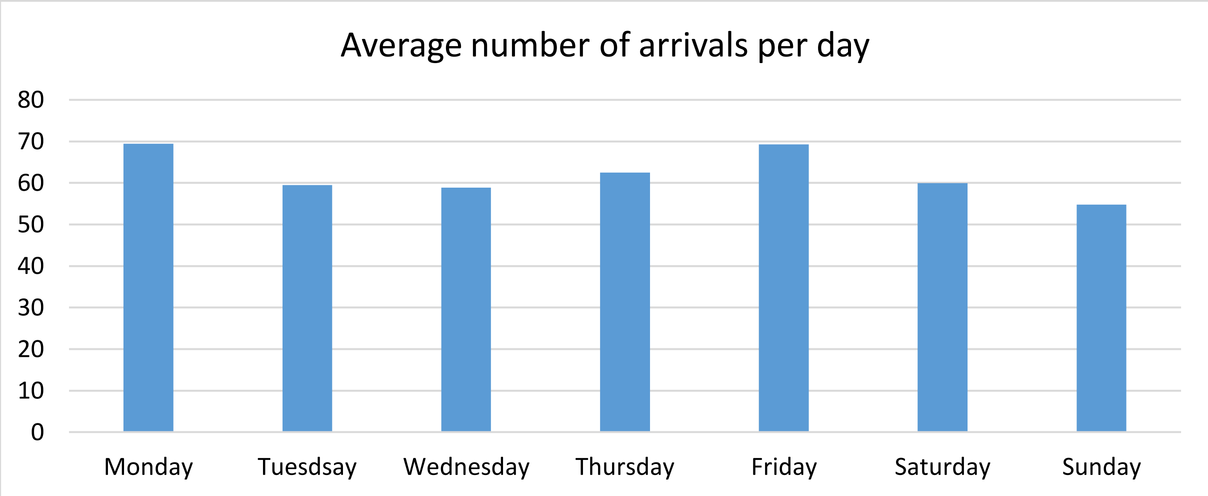


Figure 3 - Average number of arrivals per day at the ED (22707 patients, data from 2015, data retrieved from Chipsoft)

In Figure 4 we analyse the arrival patterns for each day of the week at the ED. Based on visual judgement, we assume that each weekday has a similar arrival pattern, i.e. they have similar busy and quiet hours. Figure 4 shows the busy and quiet hours.

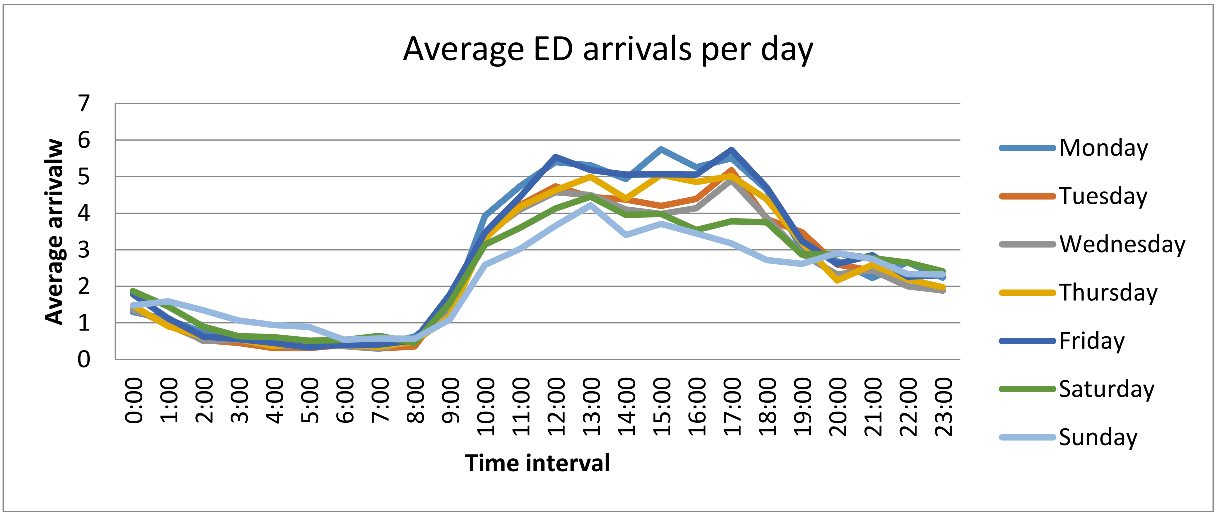


Figure 4 - Average number of arrivals per day per time interval (22707 patients, data from 2015, data retrieved from Chipsoft)

We determine the underlying arrival distributions of all days of the week. By making use of a two sample t-test, we compare the different days of the week. If the p-value is greater than 0.05, it can be concluded that there is no significant difference between the mean arrival rate of the different days. The results are given in Table 18 in Appendix A. From these observations we assume that Monday and Friday are not significantly different regarding to the number of arrivals per day. Tuesday, Wednesday, Thursday and Saturday has also no significant difference. Sunday is significantly different from each other day. We determined the underlying distribution of all days of the week by making use of Minitab version 17. The arrival patterns are tested by performing the Anderson-Darling test. The outcomes of this test and the chosen distributions for all days of the week are given in Table 19 and Table 20 in Appendix A.

Next, we look at the arrivals per week at the ED. Figure 5 shows the average arrivals per week at the ED. Through the year, no seasonal effects can be distinguished. One can identify the increase in the number of arrivals in the first week of the year. In week 30, one can see a decrease in the average number of arrivals due to the national holidays.

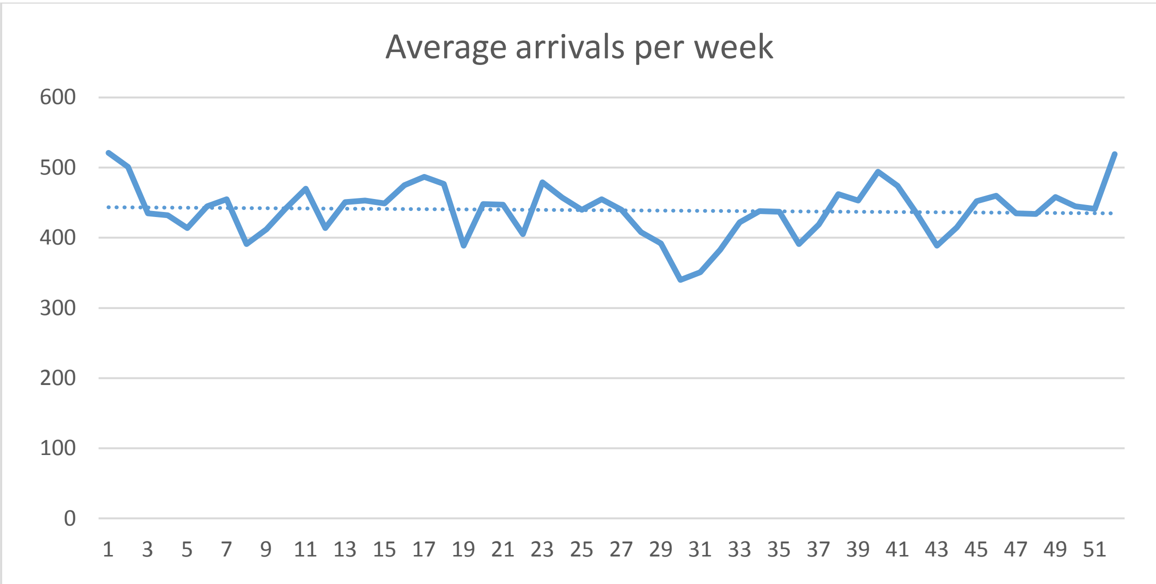


Figure 5 - Average number of arrivals per week at the ED (22707 patients, data from 2015, data retrieved from Chipsoft)

The best fitting underlying distribution for the average arrivals per week at the ED is also determined by performing the Anderson-Darling test. The best underlying distribution is a logistic distribution. The outcomes of this test are given in Table 21 in Appendix A.

2.3.2 Arrivals at the Acute Medical Unit

First, we analyse the average number of arrivals for each day at the AMU. We use data of all acute patients which are included in the criteria of the AMU from all full weeks of 2015. Figure 6 demonstrates the busy and quiet days. Monday and Friday can be identified as the busiest days. Wednesday can be identified as a relatively quiet day.

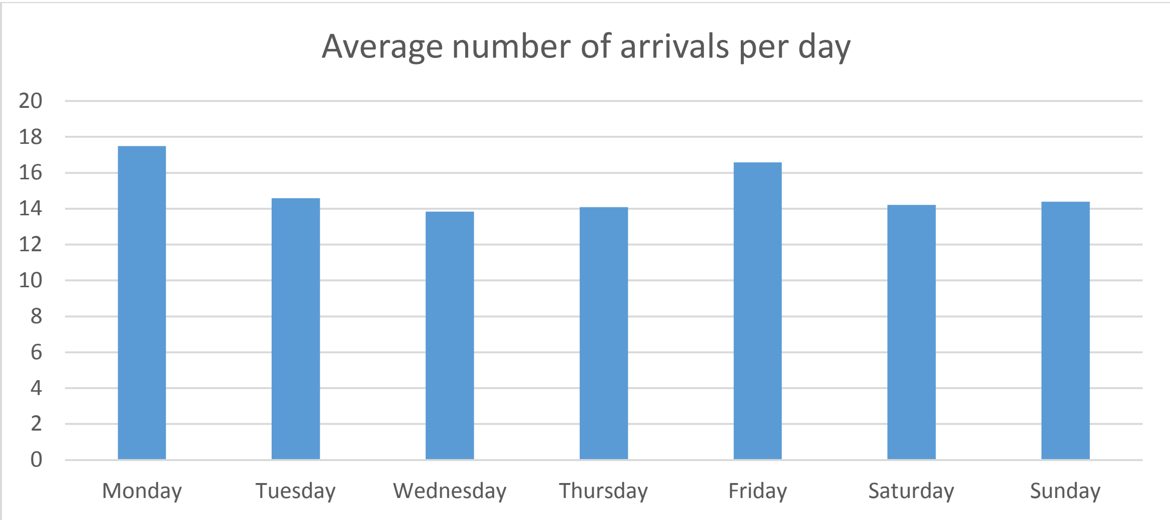


Figure 6 - Average number of arrivals per day at the AMU (5972 patients, data from 2015, data retrieved from Chipsoft)

Next, we analyse the arrival patterns for each day of the week at the AMU. Based on visual judgement, we assume that each weekday has a similar arrival pattern, i.e. they have similar busy and quiet hours. Figure 7 shows the busy and quiet hours at the AMU.

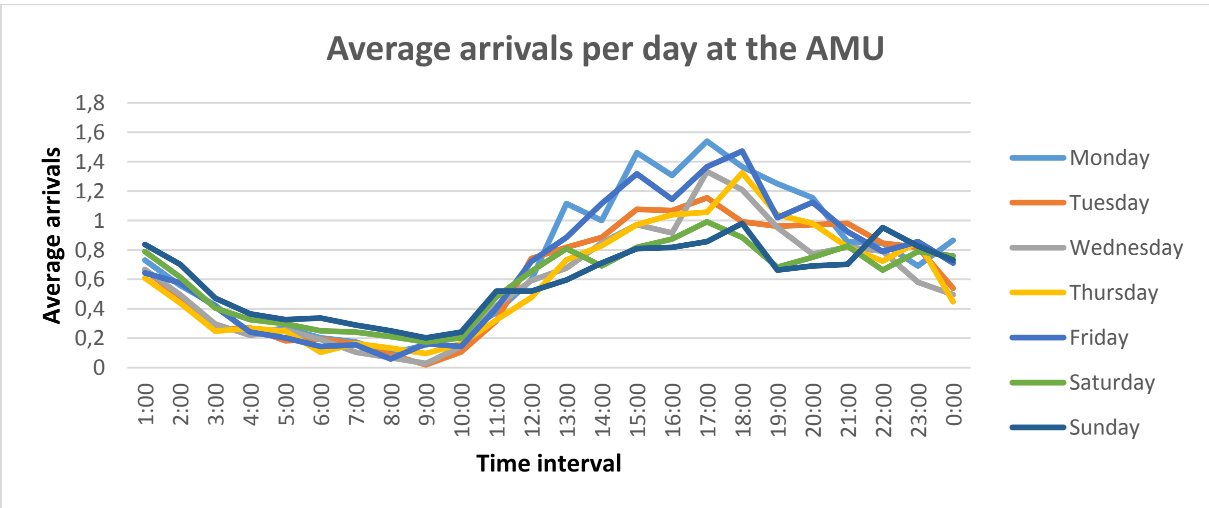


Figure 7 - Average arrivals per day at the AMU (5972 patients, data from 2015, data retrieved from Chipsoft)

In comparison with the arrivals at the emergency department in Figure 4, the increase in the number of arrivals starts about one hour later. Furthermore, a similar pattern can be recognized.

We determine the underlying arrival distributions of all days of the week. By making use of a two sample t-test, we compare the different days of the week. The results are given in Table 22 in Appendix A. From these observations we assume that Monday and Friday are not significantly different regarding to the number of arrivals per day. Tuesday, Wednesday, Thursday, Saturday and Sunday have also no significant difference. The underlying distribution of all days of the week is determined by making use of Minitab version 17. The arrival patterns are tested by performing the Anderson-Darling test. The outcomes of this test and the chosen distributions for all days of the week are given in Table 23 and Table 24 in Appendix A.

Next, we look at the arrivals per week at the AMU. Figure 8 shows the average arrivals per week at the AMU. Through the year, no seasonal effects can be distinguished. One can identify the increase in the number of arrivals in the first week of the year. In week 30, one can see a decrease in the average number of arrivals due to national holidays.

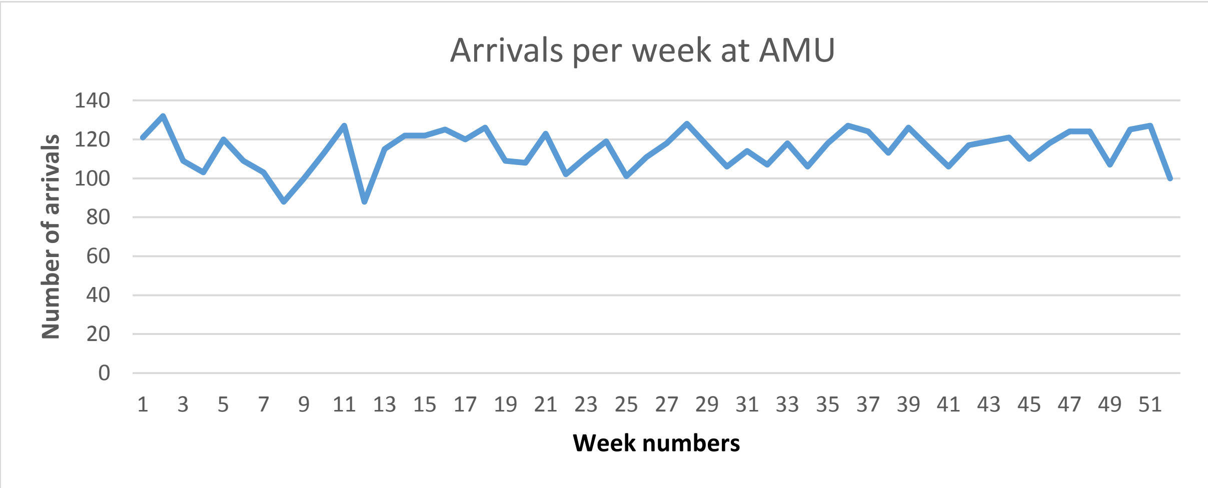


Figure 8 - Average number of arrivals per week at the AMU (5972 patients, data from 2015, data retrieved from Chipsoft)

The best fitting underlying distribution for the average arrivals per week at the AMU is also determined by performing the Anderson-Darling test. The best underlying distribution is a logistic distribution. The outcomes of this test are given in Table 25 in Appendix A.

2.3.3 Patient groups

In 2015, 22.707 acute patients have been admitted at the emergency department. 10.080 acute patients were transferred to a particular department in the hospital and 11.862 were sent home.

Others are transferred to the outpatient clinics, intensive care (IC), mortuary or ZGT Hengelo because of lack of capacity. 2231 acute patients (22%) are transferred to the ambulatory. More than 55% of the acute patients are transferred to the medical wards. The other 23% is transferred to 20 other departments like the IC, coronary care unit (CCU), paediatric department and trauma and orthopaedics.

Figure 9 shows the division of the patients that have been admitted at the emergency department per specialty. As can be seen from the figure, almost 44% of the acute patients contribute to Surgery. Internal medicine contributes to 15.5% of the acute patients. The 'Others' consists of 14 specialities like gynaecology, cardiology, plastic surgery, psychiatric, anaesthesiology, rheumatology, orthopaedic, paediatrics, oral pathology and dental surgery, throat-, nose- and otology and geriatrics which contains together 8.6%.

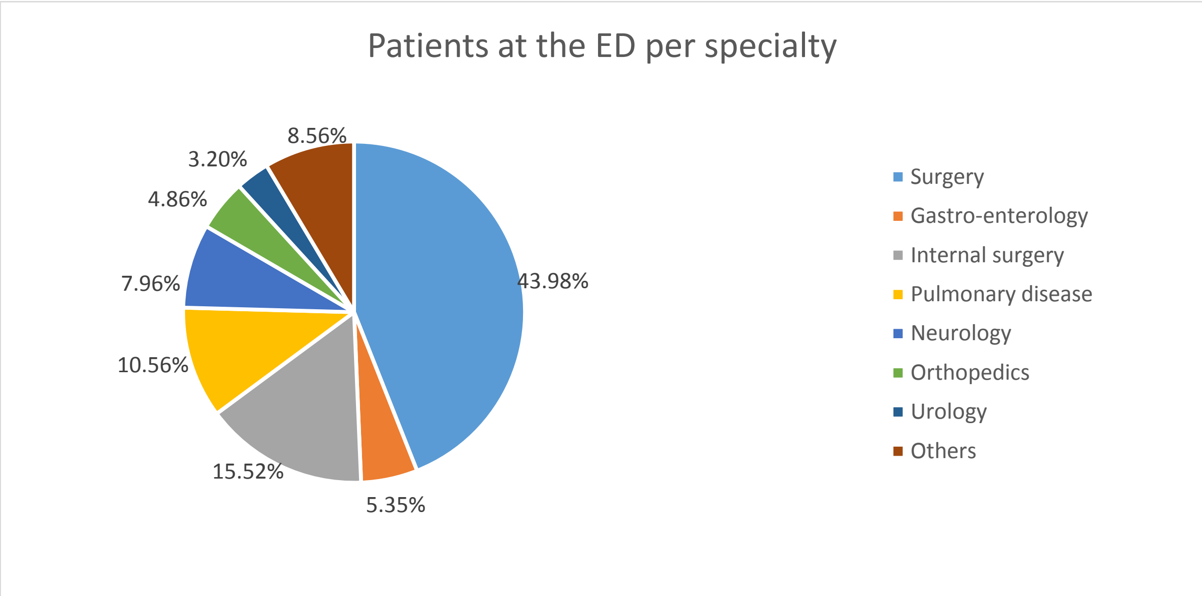


Figure 9 - Division of patients at the ED per specialty (22707 patients, data from 2015, data retrieved from Chipsoft)

In the current situation, more than 55% of the acute patients are transferred to the medical wards. Especially the wards 5N (surgery), 3Z (pulmonary medicine) and 3N (internal surgery) take care of a large part of the acute patients. Ward 3N especially takes care of the specialties internal surgery and gastroenterology. At ward 3Z, 85% of the acute patients belong to lung diseases. Over 90% of the acute patients at ward 4O belong to the specialties surgery and geriatrics. At ward 5N, almost 90% of the acute patients belong to surgery. Ward 5W especially takes care of the specialties internal surgery and gastroenterology. More than 83% of the acute patients at ward 5Z belong to surgery and urology.

Figure 10 shows the division of the patients that have been admitted at the ambulatory per specialty. As can be seen from Figure 10, more than 41% of the acute patients contribute to Surgery. Internal medicine contributes to almost 28% of the acute patients. The 'Others' consists of 14 specialities like gynaecology, cardiology, plastic surgery, psychiatric, anaesthesiology, rheumatology, orthopaedic, paediatrics, oral pathology and dental surgery, throat-, nose- and otology and geriatrics which contains together 5.8%.

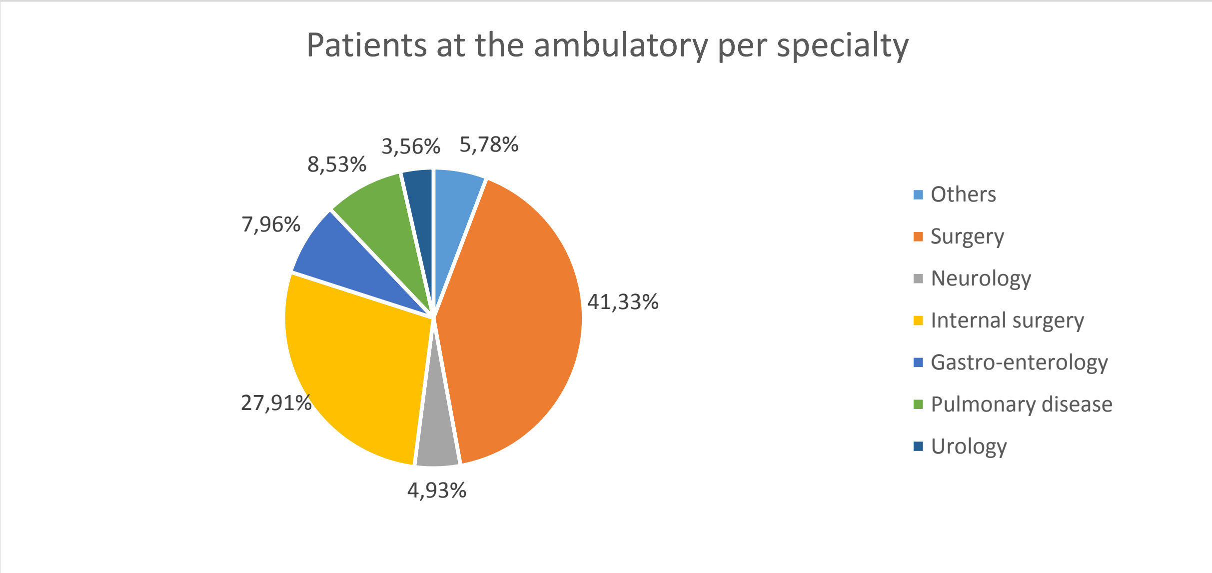


Figure 10 - Division of patients at the ambulatory per specialty (5972 patients, data from 2015, data retrieved from Chipsoft)

The following specialties will be included at the AMU: surgery, internal surgery, gastroenterology, urology, oral pathology and dental surgery, throat-, nose- and otology, plastic surgery, rheumatology, anaesthesiology and dermatology. The others specialties will not be included at the AMU.

Figure 11 shows the division of patients that will be admitted at the AMU. Surgery and Internal surgery contribute to almost 80% of all the acute admissions at the AMU. Gastroenterology contributes to 14% and there are multiple specialties that contribute for less than 1% of the acute admissions at the AMU.

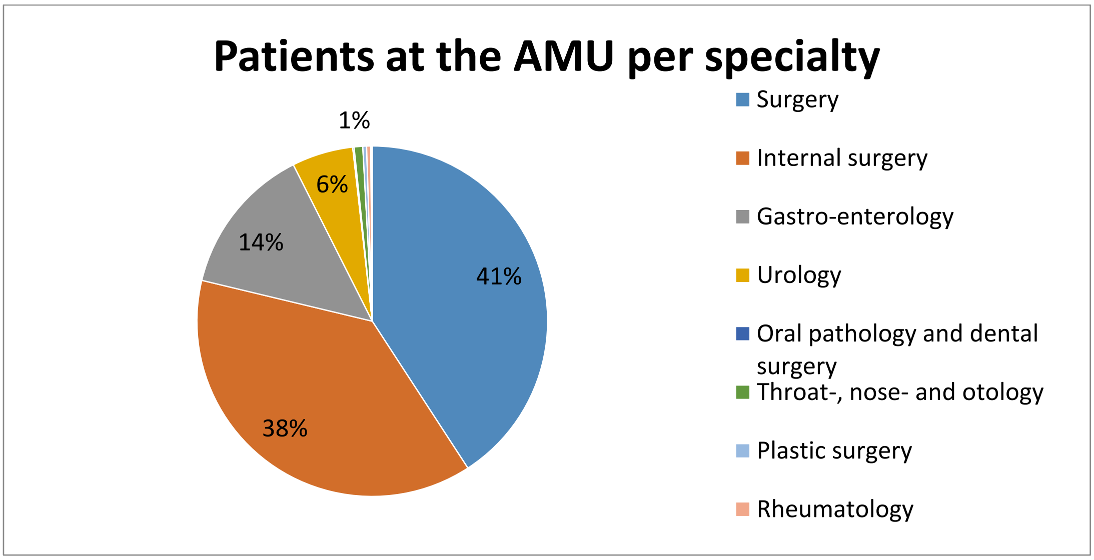


Figure 11 - Division of patients at the AMU per specialty (5972 patients, data from 2015, data retrieved from Chipsoft)

2.4 Planning and control of patients and resources

This section gives a description of the planning of acute patients and the planning of resources. Section 2.3.1 elaborates on the planning of acute patients which distinguishes between strategic, tactical and operational level. Section 2.3.2 elaborates on the planning of resources which contains bed capacity, staff and equipment.

2.4.1 Planning of acute patients

The planning of acute patients can be divided into planning at strategic, tactical and operational level. The focus in this section is on the planning of the bed capacity for acute patients.

At strategic level, a plan of the division of beds is determined each year. The number of beds made available for each specialty or ward is based on the forecast of the expected number of beds needed. A forecast about the number of beds needed per department is determined. The forecast shows how many beds should be opened in each department in order to meet the expected patient flow. A second forecast is about the expected number of beds for each specialty. This forecast shows how many beds should be opened for the anticipated patient flow for each specialty. This forecast is calculated based on several factors. This includes, among other things, the refusal change in the deployment of a certain number of beds, analysis of peak and valley load, expected grow and contraction patterns and experiences from the departments of last year.

The plan of division of the beds is determined for each week of the year. There are some reduction weeks in which the number of beds is reduced within one or more departments or specialties.

Besides these reduction weeks, there are even more beds that are closed within the construction holiday. In addition, the plan takes into account the weeks in which maintenance takes place.

ZGT consists of 26 Results-Accountable Units (RVE). Each RVE is responsible for one specialty. The RVE is among others responsible to have sufficient capacity available to take patients from the catchment area. The RVE itself ensures flexibility of the available capacity (personnel, space and resources), both during the year and for today and tomorrow. ZGT ensures flexibility of the available bed capacity by using a mapping scheme in which the beds could be shifted between specific specialties. Nevertheless, it is possible that a capacity shortage occurs. On a number of departments, beds should always be available for the throughput of patients in case of calamities. The IC should always have one bed available for calamities. The CCU should also have 2 beds available at each location and the SCU and the delivery room should also have one bed available at each location. In Table 5, the responsibilities per employee are scheduled.

Table 5 - Responsibility matrix

	Strategic	***Tactical***	***Offline operational***	***Online operational***
Board of directors	Financial framework			
Business administration manager				Declare admission stop
RVE management	*Production agreements* *Deployment of resources*	Business operations is in balance with patient supply		
Unit head			Adapt the work organization on the supply of patients	Monitoring and controlling capacity
Clinic admission office + ENW coordinator	Number of beds available for each specialty is determined for each week of the year	Regarding capacity: facilitating, signalling, advising	Takes care of the admission schedule of elective patients Regarding capacity: facilitating, signalling, advising	Coordinating the acute admissions Coordinating admission stop Regarding capacity: facilitating, signalling, advising

ZGT features a central ‘clinic admission office’ which is located in Almelo. The clinic admission office takes care of the admission schedule of all elective patients. The clinic admission office is also responsible for assigning the emergency admissions. The clinic admission office includes a bed coordinator. The bed coordinator is among others responsible for assigning acute patients to beds. This bed coordinator has insight in the number of available beds in the hospital during the day through the hospital information system. On each ward it is accurately registered in the hospital information system if a patient is discharged or a new patient is admitted at the specific ward. If the discharge date is known, this date is beforehand registered in the system. In this way, the bed coordinator will have insight in the number of beds which will be available.

At tactical level, no specific actions are performed. Within the plan at strategic level, the planning for each specific week of the year is already taken into account. At operational level, the available bed capacity is mapped once a day in a 'normal' situation. At both locations, a consultation with the unit heads of the surgical wards and the bed coordinator takes place in which the available bed capacity will be discussed. In addition, the bed coordinator has two times a day telephonic consultation with the unit head of each ward about the available bed capacity.

The clinic admission office will be informed if an acute patient has to be hospitalized. The bed coordinator assesses at which ward the patient should be placed. In case of a short admission or a temporarily observation, the patient is preferably placed at the ambulatory. Patients are admitted at the ambulatory for a maximum of 24 hours. In practice, the admission on this ward usually takes a longer time. From this ward, patients are transferred to the specific sequel ward if necessary, and otherwise transferred to a care facility or sent home. The bed coordinator communicates by telephone that a patient will be admitted at the observation ward. The appointment is that the nurses of the ambulatory pick up the patient from the ED. Within the hospital information system the patient is transferred to the observation ward. At the ambulatory, nurses start with the admission conversation and all key values and personal information is entered into the system. Every night, the nurses of the ambulatory let the clinic admission office know which patients should be transferred to another ward for a longer admission.

In other cases when a patient should not be placed at the observation ward, the bed coordinator knows through the hospital information system if there is a bed available at the appropriate ward. If there is no bed available at the appropriate ward, the bed coordinator looks at other alternative wards for an available bed by making use of the preference matrix as shown in Appendix A.

2.4.2 Planning of resources

At the ED, the ambulatory and the AMU, many resources are used. A distinction can be made between bed capacity, staff and equipment. This section provides an overview of the resources used.

Bed capacity

The ED contains 11 treatment rooms. There are also two rooms for trauma cases. The ambulatory at the 5th floor in ZGT Almelo consists of two parts: the acute admission with and without monitor observation. In total, the ambulatory has 12 beds from which 5 beds with monitor observation. The AMU will get 36 beds in total for a maximum stay of 48 hours.

Staff

We distinguish between different types of personnel at the ED. The number of personnel which is present at the ED depends on the time of the day and for doctors also on the day of the week. We distinguish between ED doctors and ED nurses. At each day, the same number of ED doctors and nurses is available. This occupation is based on historical data. For scheduling the ED doctors, there are three shifts: day, evening and night. The day shift starts at 7:00 and ends at 15:30. The evening shift is from 15:15 to 23:15 and the night shift is from 23:00 to 7:15. Each shift has fifteen minutes overlap for the transmission of information of the patients. The number of doctors scheduled on each day and shift is shown Table 6. The schedule of the nurses does not distinguish for different days. This schedule consists of six time intervals in which one or more extra nurse are added and can be seen in Table 7.

Table 6 – Number of doctors at the ED

Shift	Number of ED doctors			
	Mon-Wed	Thu	Fri	Sat-Sun
Day	6	5	5	3
Late	3	3	3	3
Night	3	3	2	2

Table 7 – Number of nurses at the ED

Shift	Number of ED nurses
7.15 – 15.45	5
8.00 – 16.30	5
9.30 – 18.00	1
11.00 – 19.30	1
15.30 – 23.15	6
23.00 – 7.30	5

At the ambulatory, we distinguish between two personnel types: nurses and nurse assistants. Like the shifts for doctors at the ED, at the ambulatory here are the same three shifts: day, evening and night. The day shift starts at 7:00 and ends at 15:30. The evening shift is from 15:15 to 23:15 and the night shift is from 23:00 to 7:15. The shifts and staff per shift are displayed in Table 8. Furthermore, there are two shifts for the nurse assistants. At each shift there is one nurse assistant available.

Table 8 – Number of nurses at the ambulatory

Shift	Number of nurses
Day	3
Evening	2
Night	2

The AMU is characterized by high volume and highly complex care. Therefore, a senior nurse formation is desirable. Per shift there are two AMU nurses with specific focus next to the AMU nurses without specific area of interest, to ensure a safe process concerning taking over of patients, support and discharge around the monitored patient category.

The AMU will have a flexible deployment of nurses and care assistants in the day-, late- and night shift. This flexible deployment of staff will be structured as follows. A distinction is made between the basic grid, minimum harmonica and maximum harmonica. If historical data shows that 25 beds will be occupied, the basic grid will be used. A service pattern of 6-4-3 will be deployed in this situation. If 30 beds at the AMU will be occupied, the minimal harmonica will be used.

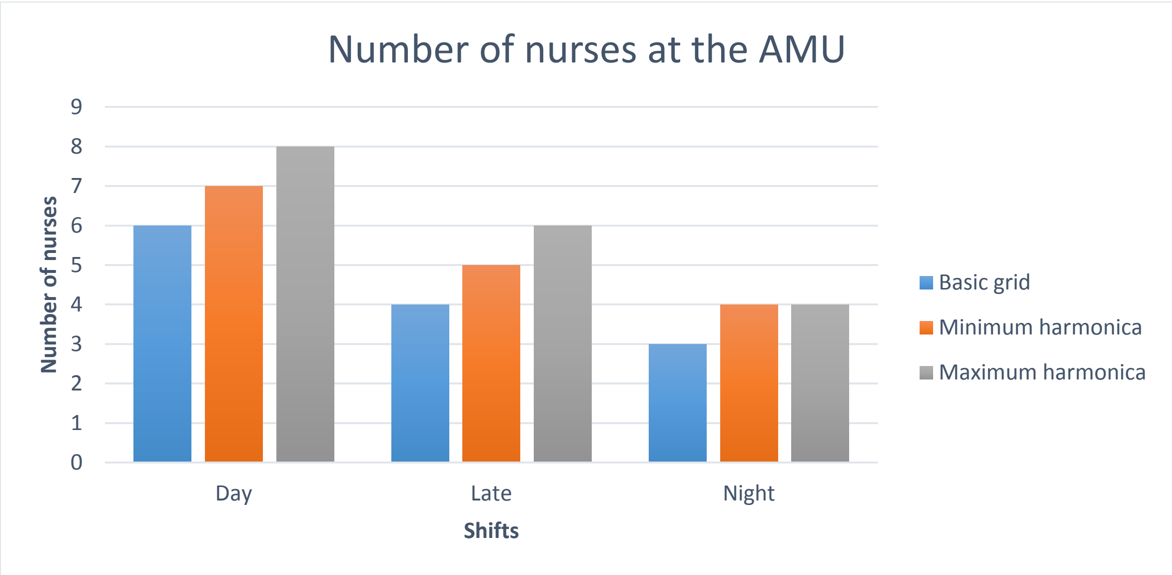


Figure 12 - Number of nurses at the AMU in each shift

During the year, there may be high fluctuations in the demand for care at the AMU. The maximum harmonica will respond to the highest fluctuations. These services are not scheduled in principle, but it is viewed at the last moment if these services are needed. In this situation, the AMU is able to respond shifting the beds up to 36 (100%). History shows that these services will be mainly needed in the first months of the year. The number of nurses and nurse assistants scheduled in each shift are shown in respectively Table 9 and Table 10.

Table 9 - Number of nurses in each shift at the AMU

Shift	Number of nurses		
	Basic grid	Minimal harmonica	Maximum harmonica
Day	6	7	8
Late	4	5	6
Night	3	4	4

Table 10 – Number of nurse assistants in each shift at the AMU

Shift	Number of nurse assistants		
	Basic grid	Minimal harmonica	Maximum harmonica
Day	4	5	6
Late	2	3	3
Night	0	0	0

Equipment

Various types of diagnostic tests can be performed. The most common diagnostic tests are lab research, MRI, CT and ultrasound. For MRI, CT and ultrasound, patients need to be transferred to the diagnostic department. More than 72% of the patients who enter via the ED make use of a diagnostic service. The probability that a certain diagnostic test will be performed is dependent of a certain specialty. The probabilities and the average number of requests of a certain diagnostic test per specialty are given Table 26 in Appendix B.

Emergency patients also make use of operating rooms (ORs). About 25% of the emergency patients need an OR. The probability that a patient needs an OR is dependent of a certain specialty. The probabilities and average number of requests per specialty that needs an OR are given in Table 27 Appendix B.

2.5 Conclusions

In this chapter we have analysed the care path of an acute patient. A patient can enter the hospital via the ED or the outpatient clinic. A critically ill patient will be transferred to a critical care unit. Other acute patients who need to be admitted are transferred to the ambulatory for a short admission or another medical ward for a longer admission. We briefly discussed the planned changes by establishing an AMU. The ambulatory will no longer exist.

We have analysed the current arrival processes at the ED, based on historical data. We have analysed the expected arrival pattern at the AMU that will be used in the simulation model. The division of patients at the ED, ambulatory and AMU are identified.

We have analysed the planning and control of patients and resources. At strategic level, each year a forecast of the expected number of beds needed for each department and/or department is made in order to meet the expected patient flow. At operational level, the clinic admission office is primarily responsible for placing acute patients within the hospital. We analysed what resources are used both at the ED, the ambulatory and the AMU. We made a distinction between beds, staff and equipment.

With the establishment of the AMU, we are interested in the most convenient location to place this department. Evidence of the effectiveness and efficacy of AMUs, facility layout problems and nurse flexibility are the main subjects of which we need more information from already published literature. Therefore, we perform a literature study in Chapter 3.

3 Literature study

In this chapter we perform a literature study in order to find research already done on the subjects concerning this study. The search strategy and search terms can be found in Appendix C. In Section 3.1, we discuss literature related to the objectives and benefits of AMUs. We also discuss the evidence of the efficacy and effectiveness and the design and operational characteristics of AMUs. Section 3.2 discusses literature about the importance of the location of an AMU, other facility layout problems and approaches to solve these problems. This section is followed by literature on flexible nurse staffing in Section 3.3. We end this chapter with a conclusion in Section 3.4.

3.1 Acute Medical Unit

Each AMU has its own peculiarities in organization and operation, but they all share common objectives and possible benefits (Scott, Vaughan, & Bell, 2009). Some objectives of an AMU are: rapid and comprehensive multidisciplinary assessment, early consultant review of admitted patients led by appropriate trained acute care physicians, rapid turnaround in pathology, radiology and other diagnostic facilities, reduced waiting times for patients at emergency departments and optimization of bed management.

The benefits include the following: more appropriate and timely assessment, diagnosis and treatment of patients leading to reduced length of stay, more organized work environment with standardized admission and discharge processes, reduced overcrowding in emergency departments and avoidance of unnecessary admissions, improved bed management and smoother patient flows, increased staff job satisfaction and more effective use of resources for the hospital as a whole (Scott, Vaughan, & Bell, 2009).

3.1.1 Efficacy and effectiveness of Acute Medical Units

Evidence of the efficacy and effectiveness of AMUs is growing, mainly focused on key performance indicators such as length of hospital stay, number of readmissions, all cause hospital mortality rate, ED waiting times and direct discharge rates. Scott, Vaughan and Bell (2009) shows that limited observational data suggest that AMUs reduce in-patient mortality, length of stay of acute patients and emergency access block without increasing readmission rates. This study also identifies that AMUs improve patient and staff satisfaction (Scott, Vaughan, & Bell, 2009). Multiple research shows that a decreased length of stay is achieved without a corresponding increase in unplanned readmissions (Scott, Vaughan & Bell, 2009; Li et al., 2010; Moloney, Bennett & Silke, 2007). Li et al.

(2010) determines that an AMU provides a decrease in overall hospital length of stay, direct discharge rate within 24 hours is significantly increased and the ED waiting time is significantly decreased. According to Rooney et al. (2008), all-cause hospital mortality is significantly improved in acute medical patients.

Articles by McNeill (2009) and Bell et al. (2013) show an improvement in patient outcomes due to early consultant review. A continuous presence of a consultant at the AMU is associated with reduced mortality (McNeill, 2009; Bell et al., 2013). Moloney et al. (2005) shows that early consultant review is associated with a reduced length of hospital stay. Another objective is to reduce waiting times for patients at the ED to access in-hospital beds (Scott, Vaughan, & Bell, 2009). Patients should not wait unnecessarily to be transported to the AMU. Therefore, patient transfer has to be organized efficiently.

From these articles we see that there is growing evidence for the efficacy and effectiveness of AMUs. Since in our study, the choice for establish an AMU is already taken, we focus on finding articles which focuses on the design characteristics and the operational characteristics of an AMU.

3.1.2 Design and operational characteristics of Acute Medical Units

While each AMU has its own peculiarities, they all share some common design and operational characteristics. One of the operational characteristics is the focus on multidisciplinary assessment (McNeill et al., 2011). This research also shows that seventy-seven percent of the AMUs stated that they had a documented operational manual and an admission policy. Just over 50% had a documented discharge policy. Seventy-seven percent of the AMUs had a defined maximum length of stay 48 hours.

Another important patient flow characteristic is the rapid turnaround in pathology, radiology and other clinical investigative services. Therefore, an AMU is preferably co-located to these investigative departments. Potential process bottleneck like e.g. waiting time to be picked up by a nurse from the AMU or the time to access for diagnostic services must be avoided (Scott, Vaughan, & Bell, 2009). Patients admitted at the AMU must have rapid access to diagnostic tests, particularly diagnostic imaging. Delays in diagnosis, and therefore treatment, have to be minimized and unnecessary hours of bed usage should be prevented (O'Neill & Courtney, 2010). The close proximity of AMUs to investigative departments will facilitate patient movement to and from these departments.

An AMU should be developed to facilitate patient-centered care across frequently involved departments like ED and investigative departments as mentioned above. In the following section we discuss more on facility layout problems and solving approaches for these problems.

3.2 Location of an Acute Medical Unit

In Section 3.2.1 we discuss the literature related to the location of an AMU. We also briefly discuss some important considerations in hospital design. Approaches for solving facility layout problems are discussed in Section 3.2.2.

3.2.1 Locating an AMU

By establishing an AMU, one has to consider the most convenient location. Locating or positioning at least one facility among several existing facilities in order to optimize (minimize or maximize) at least one objective function is also called 'Facility layout' (Drira, Pierreval, & Hajri-Gabouj, 2007). Facility layout problems are also defined as optimization problems that try to make layouts more efficient by taking into account various interactions between facilities and material handling system while designing layouts (Shayan & Chittilappilly, 2004).

Facility layout problems are integrated in many manufacturing and service organizations. Typically, they're related to the location of facilities like e.g. machines or departments in a plant. Facility layout could have an enormous impact on daily operations. Layout does dictate the distance a patient must travel between departments. The layout within a hospital also influences which staff members are likely to interact and communicate. The basic goals in developing a facility are functionality and cost savings. It is important to place the necessary departments close together, and keeping those departments apart that should not be together. Cost savings include e.g. reduction in travel times between departments and allowing for reduced staffing by placing similar job functions together. A poorly designed workspace may harm both productivity and quality. It adds not only to costs but also weakens staff morale (Ozcan, 2009). Tompkins et al. (1996) stated that a good placement of facilities contributes to the overall efficiency of operations and can reduce 20-50% of the total operating expenses.

The hospital facility layout problems have received less attention in the literature compared to the manufacturing facilities. Many hospitals are designed using old techniques which have proven to be inefficient (Janvrin, Leheta, Munarriz, & Neme, 2012). The need to provide effective and efficient care, while making quality of patient care more valuable, is a primary issue for hospitals. The productivity of a hospital is mainly affected by the way in which facilities are placed and which can improve the performance of different health care delivery processes. According to Tompkins et al. (1996), there are some considerations which are most important in hospital design. The two most important considerations are to minimize the distances between patient care rooms and nursing units and to facilitate patient movements in the vertical direction to different floors (Tompkins, et al., 1996).

A limited amount of research has been conducted at the intersection of AMUs and the geographical location within a hospital. There is no evidence whether geographical location of the acute medical unit is significant. Though it has often been suggested that a position within, or in very close proximity to the emergency department (ED) is very important. Cooke, Higgins and Kidd (2003) argue that an AMU should be in a well-defined area. Ideally this is within the emergency department or directly adjacent to it. This study has noted that 93% of the acute medical units were located near the emergency department (Cooke et al., 2003). Medical diagnostic facilities, therapeutic service departments and treatment facilities are among the most visited hospital units by patients. Scott et al. (2009), Cooke et al. (2003) and Moloney (2005) stated that the AMU is preferably located near the ED and the diagnostic facilities such as the laboratory and radiology because the transfer between the units will commonly occur.

There are several facility layout papers that try to determine the most convenient location to minimize the transportation times. In the next section we focus on possible approaches for solving facility layout problems.

3.2.2 Approaches for solving facility layout problems

A number of researchers investigated facility layout problems in depth (Meller, 1996; Meller & Bozer, 1997; Kochhar & Heragu, 1998; Lin, 1999). Most research related to facility layout problems are considered as an optimization problem. Such a problem can be viewed as a quadratic assignment problem (QAP) and could be assigned to the class of NP-hard problems (Shayan & Chittilappilly, 2004). According to Sahin (2010), a facility layout problem features both qualitative as quantitative solutions. Literature published into facility layout problems could be divided into two major categories: algorithmic and procedural approaches. The majority of the published articles are concentrating on algorithmic approaches. According to Yang and Kuo (2003), algorithmic approaches simplify both design constraints and objectives in order to reach an objective function. Procedural approaches focus on both qualitative and quantitative objectives in the design process (Yang & Kuo, 2003). The design process is often divided into several steps which are solved sequentially. According to Yang, Su and Hsu (2002), neither an algorithmic approach nor a procedural approach is necessarily effective in solving facility layout problems. Rosenblatt (1979) initially proposed research on combining both qualitative and quantitative relationships in a single objective function, instead of considering them individually. This research is based on the Quadratic Assignment Problem (QAP) that includes both qualitative and quantitative relationships by adding them together (Rosenblatt, 1979).

A proposed methodology for solving facility layout problems should feature both the quantitative and qualitative aspects. We found multiple articles that discuss an integrated approach for solving facility layout problems that features both merits of the algorithmic and procedural layout design approaches.

Shang (1993) would like to address the qualitative issue subjectively and systematically, while at the same time dealing with the quantitative matter objectively and analytically. Analytic Hierarchy Process (AHP) is used to address the qualitative aspects of the facility layout problem. A QAP is formulated to combine the qualitative and quantitative objects. Finally, simulated annealing search technique is used to find a near optimal solution (Shang, 1993). Shang and Sueyoshi (1995) developed a framework which consists of three individual modules: AHP, a simulation module and an accounting procedure. These modules are unified through DEA. Both AHP and simulation models are used to generate the necessary outputs for the DEA whereas the accounting procedure determines the required inputs. Multiple efficient DMUs are identified in the DEA solution (Shang & Sueyoshi, 1995).

The AHP is a multi-criteria decision-making approach. It is a decision support tool which can be used to solve complex decision problems (Saaty, 2008). The AHP uses a multi-level hierarchical structure of objectives, criteria, sub-criteria and alternatives. The outcomes are obtained by using pairwise comparisons. These comparisons are used to obtain the weights of the importance of the decision criteria, and the relative performance measures of the alternatives in terms of each individual decision criterion. The AHP contains the following steps.

1. Define the problem and determine the kind of knowledge sought
2. Structure the decision hierarchy from the top with the goal of the decision, the objectives, the criteria and the alternatives
3. Construct a set of pairwise comparison matrices. Each element in an upper level is used to compare the elements in the level immediately below with respect to it.
4. Use the priorities obtained from the comparisons to weigh the priorities in the level immediately below. Do this for every element. For each element in the level below add its

weighed values and obtain its overall or global priority. Continue this process of weighing and adding until the final priorities of the alternatives in the bottom are obtained.

To make comparisons, a scale of numbers from 1 to 9 is used that indicates how many times more important or dominant one element is over another element with respect to the criterion or property with respect to which they are compared.

Yang and Kuo (2003) and Ertay, Ruan and Tuzkaya (2006) proposed an integrated approach of AHP and Data Envelopment Analysis (DEA) to solve a facility layout problem. Yang and Kuo (2003) used a computer-aided layout-planning tool to generate a considerable numbers of layout alternatives as well as to generate quantitative decision making unit (DMU) outputs. AHP weighted the qualitative performance measures and DEA was then used to solve the multi-objective layout problem. Ertay et al. (2006) developed a decision-making methodology based on DEA, which uses both quantitative and qualitative criteria. A computer-aided layout-planning tool is used to facilitate the layout alternative design processes as well as to collect quantitative data by using exact data. AHP is then applied to collect qualitative data. DEA is used to solve the layout design problem by simultaneously considering both quantitative as qualitative data.

Shahin (2011) proposed an integrated framework based on simulation, AHP, Quality Function Deployment (QFD) and Multiple Criteria Decision Making (MCDM) for facility layout design improvement and optimization. Simulation has been used to determine the quantitative measures and AHP is applied to determine the weight of qualitative measures for layout alternatives. QFD has been used to determine weights of criteria and the importance of the alternatives. Thereafter, Topsis approach has been used for ranking the alternatives and identifying the best alternative (Shahin, 2011). Mohamadghasemi and Hadi-Vencheh (2012) present an integrated methodology based on the synthetic value of fuzzy judgments (SVFJ) and nonlinear programming (NLP). The goal of this study is to incorporate qualitative criteria in addition to quantitative criteria to the facility layout problems. The facility layout patterns are generated by a computer-aided layout-design tool, CRAFT. The quantitative criteria are calculated by appraising these patterns. The SVFJ is applied to collect the performance measures related to the qualitative criteria. NLP is proposed to solve the problem. (Mohamadghasemi & Hadi-Vencheh, 2012)

An overview of the different integrated approach is listed in the Table 11.

Table 11 - Overview of the integrated approaches from the literature

	Evaluation tools for quantitative criteria	*Evaluation tools for qualitative criteria*	*Problem solved via*
Shang (1993)	QAP	AHP	Simulated annealing
Shang (1995)	Simulation	AHP	DEA
Yang and Kuo (2003)	Handheld computing	AHP	DEA
Ertay et al. (2006)	Handheld computing	AHP	DEA
Shahin (2011)	Simulation	FAHP	Topsis
Mohamadghasemi and Hadi-Vencheh (2012)	CRAFT software	SVFJ	NLP model for ranking the layout patterns

Since we only have one alternative and one facility to be located, we conclude that the DEA is not suited in this case. The Topsis is also not appropriate in this study. We will use simulation to evaluate the quantitative criterion. Qualitative criteria will be evaluated by AHP to determine the weight of these qualitative criteria. Thereafter we consider simultaneously both quantitative as qualitative data.

3.3 Conclusions

From the literature we have seen that there is growing evidence for the efficacy and effectiveness of AMUs. AMUs reduce all-cause hospital mortality, length of stay of acute patients and ED waiting times. Direct discharge rate will be increased. The location of an AMU is important to facilitate patient-centered care across frequently involved departments.

A limited amount of research has been conducted at the intersection of AMUs and the geographical location within a hospital. In hospital design it is important to minimize the distances between patient care rooms and nursing units and to facilitate patient movements in the vertical directions to different floors in order to increase the productivity and efficiency.

In the literature, several papers focus on approaches for solving facility layout problems in order to make layouts more efficient by taking into account various interactions between facilities. A proposed methodology for solving facility layout problems should feature both the quantitative and qualitative aspects of such a problem. We discuss the several integrated approaches that features both quantitative and qualitative criteria used in solving facility layout problems. In our research, simulation will be used to evaluate the quantitative measures and qualitative criteria will be evaluated by AHP to determine the weight of qualitative measures.

In Chapter 4 we explain the simulation model we build and the experiments we perform with this model.

4 Simulation model

This chapter provides an overview of the simulation model. The conceptual model is described in Section 4.1. Data gathering methods are discussed in Section 4.2. The verification and validation are given in respectively Section 4.3 and Section 4.4. In Section 4.5 we described the different experiments we performed, we performed a sensitivity analysis and the warm-up period and the required number of replications is determined. We end this chapter with a short conclusion in Section 4.6.

4.1 Conceptual model and assumptions

In this section, we describe the basic structure of the simulation model and discuss some important assumptions that are made. The simulation model uses a Poisson distribution to determine the number of arrivals during a specific time interval for arrivals at the AMU determined from historical data discussed in Section 2.2.1 and 2.2.2.

A patient arrives at the AMU, the events shown in the flowchart in Figure 13 are triggered. Nurses regularly transport patients. The number of trips that employees make between multiple departments is a quantitative measure that can approximate the cost of having the two departments far apart. An acute patient who has to be admitted at the AMU will be picked up at the ED by a nurse and will be transferred to the AMU. The transportation time a nurse is busy with taking the patient from the ED to the AMU will be registered. At the moment of arrival of the patient at the AMU, several related variables are assigned to the patient, e.g. specialty type, the need for an OR and the need for diagnostic services. In case a patient needs to go to the OR for surgery, the same activity takes place. The transportation times of nurses to bring the patient to the OR and get back to the AMU will also be registered. In case a patient needs diagnostic services, a nurse assistant will bring the patient to the diagnostic department instead of a nurse. The patient will also pick up again by a nurse assistant. These transportation times of the nurse assistant will also be registered. When the end of the LOS of a patient is reached, the patients are discharged from the AMU to home or another medical ward.

As mentioned above, we assume that the arrival of patients at both the ED and the AMU follows a Poisson distribution. This means that the number of arrivals in a time interval of length s is a random variable with parameter λ. According to Law (2007), a stochastic process is said to be Poisson if:

- Customers arrive one at a time

- The number of arrivals in a time interval is independent of the number of arrivals in an earlier time interval
- The number of arrivals is independent from the time of the day.

The first two properties apply to arrivals at the AMU. The third property is violated by the arrival processes in this case. However, when we take a relatively short time interval, the arrival rate is reasonably constant over this interval and the Poisson distribution is a good model for the arrivals at the AMU. Therefore we take a time interval of one hour. The average number of arrivals differs per hour, per day and per week.

We made some other assumptions in building the simulation model.

- Arrivals take place at the beginning of an hour.
- A nurse or nurse assistant is always directly available to pick up the patient from different departments.
- If the maximum capacity of the AMU is reached, a new arrival will be transferred to the waiting room.
- A patient can be assigned to any of the beds at the AMU, there is no distinction in beds.

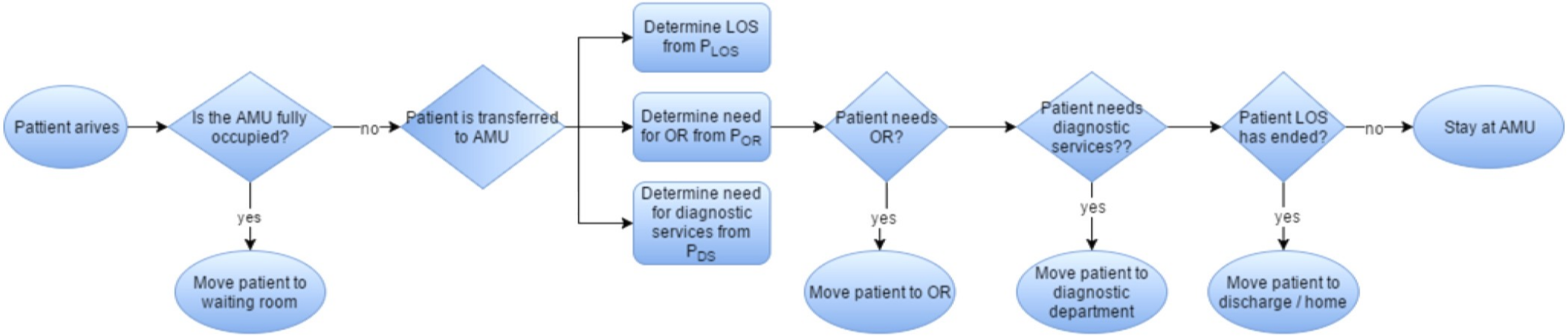


Figure 13 - Conceptual model

4.2 Data gathering

For the input of the simulation model we used data from the hospital information system ChipSoft. ChipSoft is used in the entire hospital. This means that ChipSoft contains all data regarding the arrivals and departures of all acute patients, different wards the patient has visit, length of stay of the patients etc.

We received documents of all acute patients in 2014 and 2015. We only used data of 2015 since the number of acute arrivals is significantly increased in 2015 with respect to 2014. A total of 22,707 admissions were included. From this data we derived the average arrivals per hour, per day and per week at the AMU discussed in Section 2.3.2.

We have received documents of all acute patients admitted to a medical ward and all the mutations they made within the hospital like transfers to another department, admission and discharge date and times etc. We identified the acute patients who enter the medical ward via the ED or an outpatient clinic. We filtered the acute patients who will be admitted at the AMU according to the inclusion criteria. From this data we derived the average arrivals per hour, per day and per week at the AMU discussed in Section 2.3.2. The input for the Poisson arrival rates for acute patients at the AMU are shown in Table 29 in Appendix D. The week factors are shown in Table 30 in Appendix D. The week factor refers to the total arrivals in a week divided by the average number of arrivals per week. On the basis of a week factor, possible seasonal effects were identified. From the same data we also derived the LOS of patients at the AMU. Patients admitted at the AMU can stay for a maximum of 48 hours. Since we didn't find a distribution that fits the data, we made a histogram and calculated the chances of LOS in a predetermined time interval. . The LOS distribution of patients at the AMU is shown in respectively Table 31 Appendix D.

We derived data from all patients who needed an OR or diagnostic services. From this data we identify the acute patients undergoing surgery or diagnostic services within 2 hours after admission at the AMU. The probabilities and the average number of requests for an OR or a certain diagnostic test per specialty are given in Appendix B.

4.3 Implementation and verification

Before we can use the results of the simulation model in decision making, we first have to check whether the assumptions are correctly translated into the simulation model. According to Law (2007), verification is defined as determining whether the conceptual simulation model has been correctly translated into a computer program. To check the correctness of the model implementation, different techniques can be used to debug the computer program of a simulation model.

The first technique to verify is to debug the model (Law, 2007). The model is programmed by using several sub-programmes in order to easily find possible errors. The simulation model is debugged while programming the model with the debugging option of Plant Simulation. This was an iterative processing during the programming phase.

Another technique we used in order to verify the simulation model is observing the animation of the simulation model. A difference between the model and reality is the path of the acute patients through the hospital admitted via the ED. Some of the acute patients at the ED are transferred to the AMU, other patients are sent home and the critically ill patients are admitted to a critical care unit. The CCU is not considered in the simulation model given the scope of this study. The acute patients at the ED leave the system after their LOS has passed. Another Poisson distribution is generated for the arrivals at the AMU to process the arrivals as accurate as possible. Another difference between the model and reality is that nurses and nurse assistants are always directly available to transport the patients between the different departments. In reality, nurses have to finish the care they provide to a patient at that moment. The time a patient will pick up from the ED will therefore be later in reality.

The analysis shows that the simulation model does not perfectly translate the real process into the simulation model. However, the model runs correctly. Based on the goal of this research and level of detail, the model is correctly translated and can be used well for the purposes of this research. In the next section we will validate the output of the simulation model.

4.4 Validation

Validation is the process of determining whether a simulation model is an accurate representation of the system, for the particular objectives of the study (Law, 2007). Law describes several techniques to validate a simulation model. The most definitive test of a simulation model's validity is to establish that its output data closely resemble the output data that would be expected from the actual system (Law, 2007). To validate the model, we compared the output data to those from the existing system itself. If the two sets of data compare "closely", then the model of the existing system is considered "valid".

To assess the model's validity, we compare the historical data with the output of the simulation model. An important aspect of the model is the number of arrivals during each time interval at both the AMU. We calculated the arrivals per hour, per day and per week to simulate the arrival pattern during each day. We compare the average number of admissions per day and per week from the existing system with the output of the simulation model. We also compare the average LOS of both the patients at the AMU with the output of the simulation model. The output is shown in Table 12.

Table 12 – Comparison historical data vs. output simulation model

	Historical data (2015)	Simulation model	Difference (Δ%)
Avg admissions per week at AMU	115	116	0.87%
Avg LOS AMU	39:41:53	39:18:18	0.99%

From Table 12, the conclusion can be drawn that the output of the simulation model is in line with the historical data on the average number of admissions per week at the AMU. We also show the number of arrivals per time interval at the AMU. This is graphically shown in Figure 14.

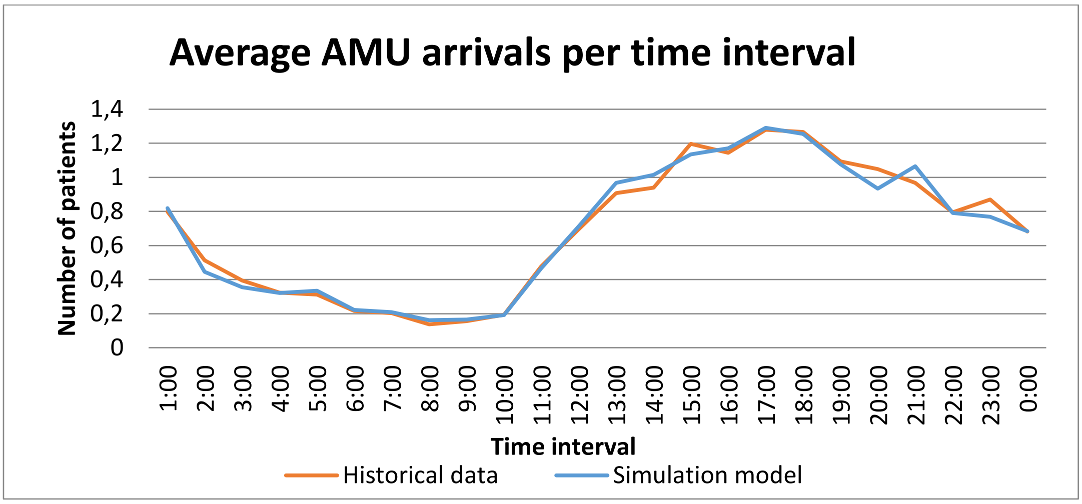


Figure 14 - Comparison of historical data with simulation model output

In Figure 14 we see that the output of the simulation model for the AMU arrivals is in line with the historical data. By comparing the average admissions per week, average LOS and the average arrivals per time interval at both the ED and the AMU, the conclusion can be drawn that the simulation model is valid.

4.5 Experiment approach

In Section 4.5.1 we present the different scenarios used in this study. We discuss the sensitivity analysis we perform in Section 4.5.2 and in Section 4.5.3 we discuss the number of replications we use for our simulation model.

4.5.1 Scenarios

Since we only have two interventions in this study we determine multiple scenarios in order to see what happened with the output of the simulation model if scenarios are changed.

The first intervention is the AMU established at the 5th floor. In the second scenario, the AMU is established near the ED at the ground floor. The inputs and processes remain the same within these interventions. We perform different scenarios to see whether output changes. In the first scenario the arrival rates are based on data of 2015. Since it is a possibility that the specialty lung diseases will also be one of the inclusion criteria of the AMU, the second scenario is based on the arrival rates in 2015 including the acute arrivals of lung diseases. The number of acute arrivals is significantly increased with just over 10% in 2015 with respect to 2014. Therefore, the last scenario is based on the current arrival rates including lung with 10% growth with respect to 2015.

4.5.2 Sensitivity analysis

In this section we perform a sensitivity analysis. By performing a sensitivity analysis we are interested in changes in output when the input to the simulation model is altered. We examine a change in the number of patient arrivals at the AMU. When changing the number of patient arrivals at the AMU, we identify the robustness of the output.

Since we used historical data to determine the number of arrivals to the AMU, we are interested in the consequences of the transportation times when these input changes. The total transportation times is shown for 90% of the arrivals up to 120% of the arrivals. This is determined in steps of 10% in the simulation model. The results are shown in Figure 15.

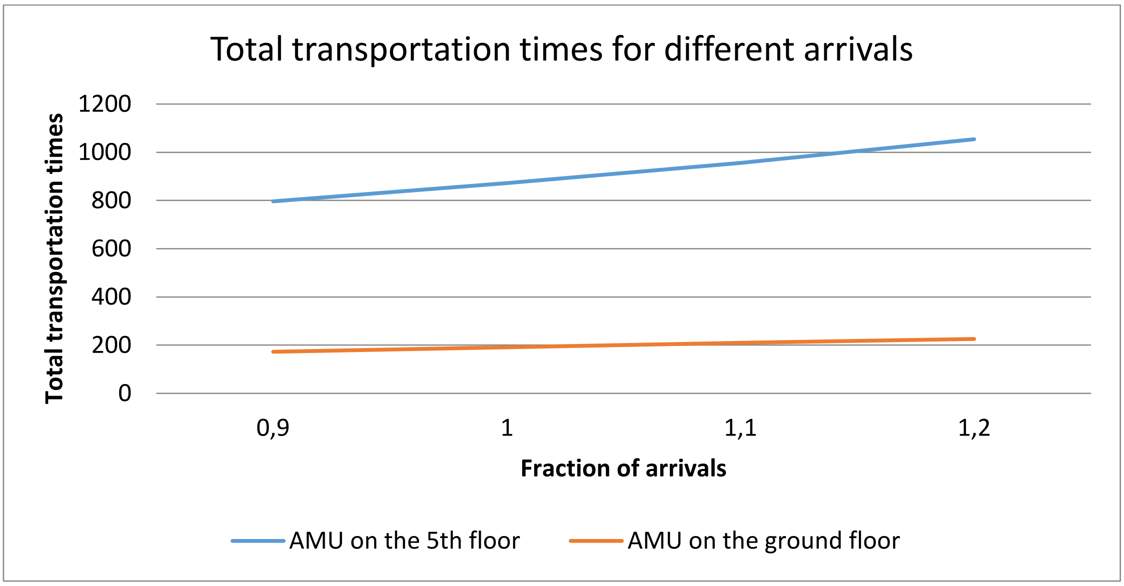


Figure 15 - Sensitivity of arrivals, results from the simulation model

Figure 15 shows that the total transportation times increases when the arrivals increase. The total transportation times increase relatively more if the AMU is located on the 5th floor in contrast to the situation in which the AMU is location near the ED on the ground floor since the transportation times to the ED, the ORs and the diagnostic department are significantly higher than the transportation times concerning an AMU on the ground floor.

4.5.3 Number of replications

In this section we determine the number of replications required for each experiment. The way in which simulation experiments are designed and analysed is dependent on the type of the simulation (Law, 2007). Law distinguishes between two types of simulation: terminating and non-terminating simulation. In this study we are dealing with a non-terminating simulation. There is no natural event that ends the simulation run. In Appendix E1 we describe in detail how the warm-up period is determined. In short, we use the graphical method of Welch's, which can be used when a steady state mean needs to be estimated for a non-terminating simulation (Law, 2007). We calculate the moving average over a large window. The warm-up period is chosen as the time it takes for the moving average to converge. The warm-up period is chosen to be 26.5 days.

Since we want reliable values for the performance measures, we need to calculate the required number of replications. The confidence interval for the measure does not get too wide. Law describes two strategies for constructing point estimates and confidence intervals. We use a fixed-sample-size procedure as suggested by Law (2007). In Appendix E2 we show in more detail what the required number of replications are when we use a confidence interval of 95% and a relative error of 10%. These calculations show that we need a minimum number of 2 replications.

4.6 Conclusions

In this section we presented the experimental design of our research. We have discussed the conceptual model and the inputs we used and the assumptions we made in the simulation model. We have discussed the way in which data is gathered and the data which is used in the simulation model.

We verified and validated the simulation model. The validation was mainly focused on the number of arrivals at both the ED and the AMU since these inputs are crucial for the output of the simulation model. We concluded that the output of the simulation model is in line with the historical data by comparing the average LOS, average admissions per week and the average admissions per time interval at both the ED and the AMU.

In this research we perform 6 experiments. We examine two interventions, namely the situation in which the AMU is established on the 5th floor and the situation in which the AMU is established near the ED on the ground floor. Each intervention contains three scenarios in which we changed the inputs of the arrival rates at the AMU: arrival rates at the AMU based on data of 2015, arrival rates based on data of 2015 including the arrivals of lung diseases at the AMU and arrivals rates based on 2015 including lung and with a grow of 10% with respect to 2015. Next to these experiments, we also perform a sensitivity analysis. Since the simulation model is a non-terminating simulation, we use a warm-up period of 27 days and a run length of one year. We perform 2 replications in order to find reliable performance measures.

In chapter 5 we discuss the results of the different experiments we performed with the simulation model. We also discuss the results of the AHP analysis.

5 Results

This chapter starts with a description of the relevant key performance indicators (KPIs) in Section 5.1. In Section 5.2 we describe the results of the different experiments we performed. The results of the AHP analysis are discussed in Section 5.3 and we end this chapter with a short conclusion in Section 5.4.

5.1 Key performance indicators

In this section, the key performance indicators are identified. Performance indicators are obtained from hospital documentation and from interviews with personnel. In order to compare the interventions, we have to measure the performance of the different situations.

Total transportation time

Since we would like to make layouts as efficient as possible, we would like to minimize the total transportation time. Long distances that patients, medicine, and information have to travel contribute to inefficient practices. In this research, total transportation time could be divided into different components: transportation time to/from ED, transportation time to/from diagnostic departments and transportation time to/from ORs. The total transportation time can be calculated by the sum of the total transportation times.

$$\begin{aligned} &Total\ transportation\ time \\ &\quad = \sum transfer\ time\ to/from\ ED + transfer\ time\ to/from\ diagnostics\ department \\ &\quad + transfer\ time\ to/from\ OR \end{aligned}$$

Transportation times of nurses per time interval

It is obvious that the transportation times from the ED to the AMU on the ground floor is significantly less than from the ED to the AMU on the 5th floor. Since we do not know how often assistance at the ED or AMU from nurses of this departments is required, we want to minimize the time nurses are engaged in patient transportation per time interval in the current situation. The more nurses are engaged in transportation, the less they have for direct patient related care at the AMU. To ensure patient safety and optimal quality of care, we want to minimize the time nurses are engaged with transport of patients.

5.2 Results

We start this section with the results of the different experiments we performed with the simulation model based on the total transportation costs in Section 5.2.1. Section 5.2.2 shows the results of the AHP analysis.

5.2.1 Results simulation model

We performed six experiments with the simulation model, three for each intervention as explained in Section 4.5.1. The results of the total transportation times and costs are shown in Table 13.

Table 13 - Results from the simulation model based on the total transportation times

	5th floor			*Ground floor*		
	Current arrivals	Current arrivals including lung	Current arrivals including lung plus 10% growth	Current arrivals	Current arrivals including lung	Current arrivals including lung plus 10% growth
Avg. per year (hrs)	1090.6	1349.44	1461.09	295.22	372.29	386.08
Avg. per week (hrs)	20.97	25.95	28.10	5.68	7.16	7.42
Avg. per day (hrs)	3.00	3.71	4.01	0.81	1.02	1.06
FTE	0.71	0.88	0.95	0.19	0.24	0.25
Costs in Euros (€)	23,931	29,745	32,224	6,133	7,819	8,182

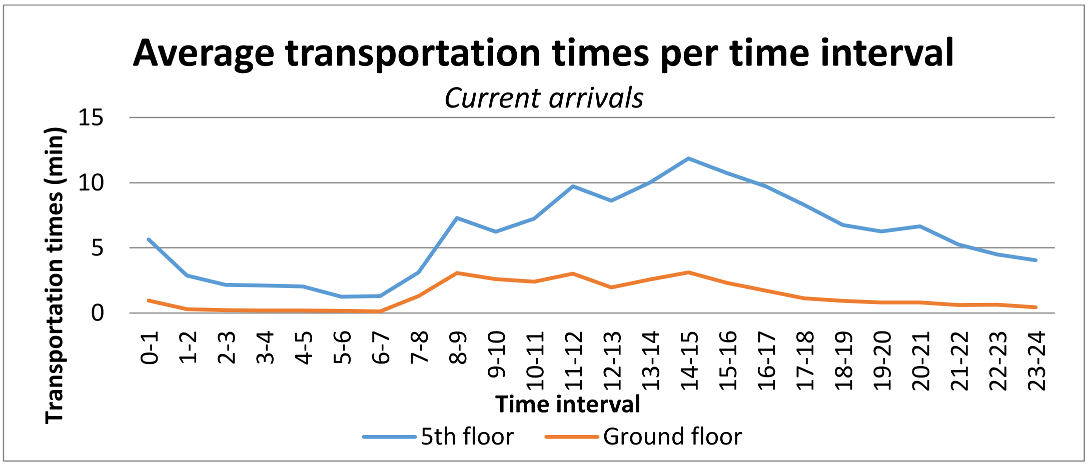
A nurse is available for 1540 hours per year. In Appendix F, an overview is given of the gross and net hours for one FTE and the costs that need to be taken into account. To determine difference in the total costs per year we divide the total transportation times by the net hours of one FTE per year and then multiply with the average year salary of a nurse or nurse assistant at the AMU. How the average year salary of a nurse is calculated is shown in Appendix F.

We calculate the differences between the two interventions by means of total FTEs and costs in Euros as can be seen in Table 14. A difference greater than zero means a higher value for the intervention in which the AMU is situated on the 5th floor compared to the intervention in which the AMU is situated on the ground floor.

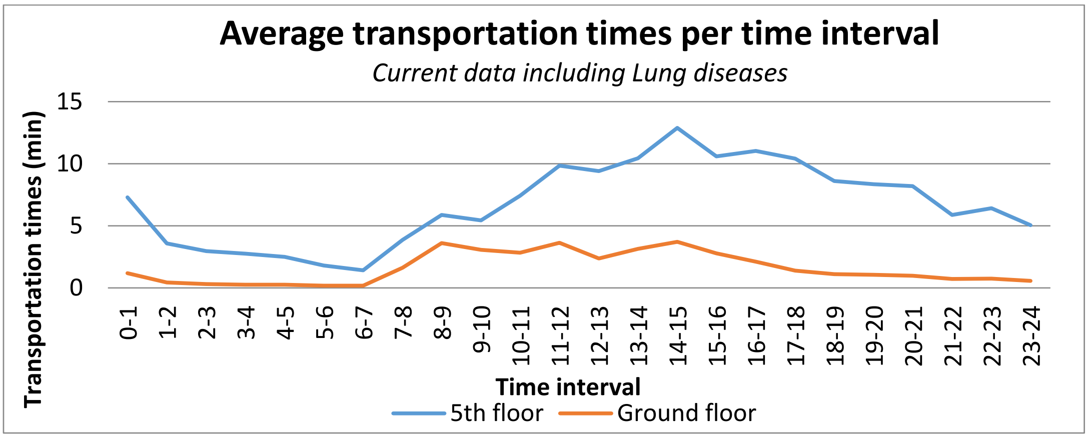
Table 14 - Differences between the two interventions by means of FTEs and costs

	Δ in FTE	*Δ in Euros*
Current arrivals	0.52	17,798
Current arrivals including lung	0.64	21,923
Current arrivals including lung plus 10% growth	0.70	24,042

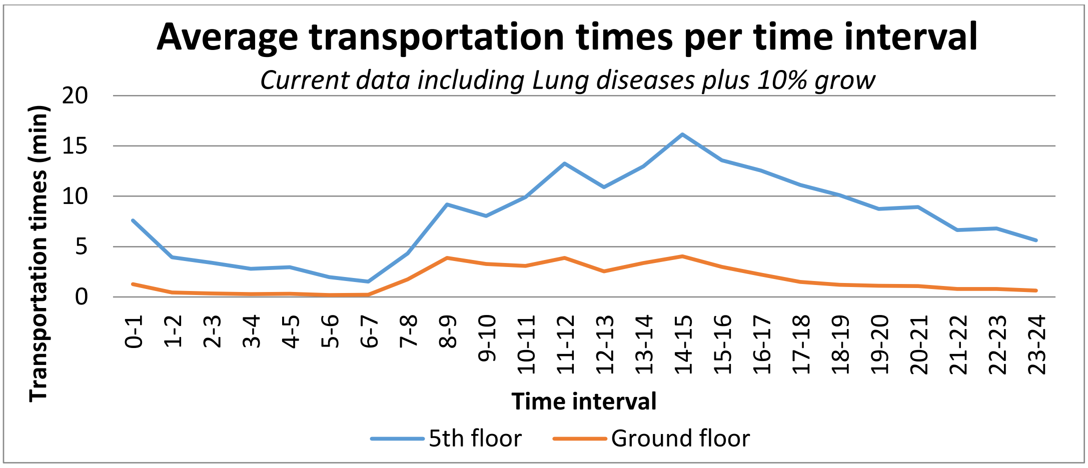
We calculated the average transportation times per time interval for each scenario. These transportation times are displayed in Figure .



(a) Average transportation times per time interval based on current arrivals



(b) Average transportation times per time interval based on current arrivals including lung diseases



(c) Average transportation times per time interval based on current arrivals including lung diseases plus 10% grow

Figure 16 - Average transportation times per time interval per intervention for each scenario

Figure 16 shows that in each scenario the average transportation times increase from approximately 8.00 h. There is a peak around 14.00-15.00 h. This corresponds to the pattern of arrivals at the AMU.

It is therefore logical that the transport times are higher in this time interval. In Figure 13(c) and the case in which the AMU is located on the 5th floor, nurses are on average more than 15 minutes engaged with transporting patients. This means that they are 25% of the time not available at the AMU to deliver direct patient related care. In the other intervention in which the AMU is located on the ground floor, the average transportation time in this interval is approximately 4 minutes (6.7%) in which nurses are not available at the AMU. After this peak, the average transportation times per time interval decreases.

5.2.2 Results AHP analysis

The AHP analysis is performed in order to provide objective weights against a set of qualitative layout evaluation criteria. The qualitative performance measures are determined by discussions with management and by general layout guidelines. The qualitative criteria used in this study are: 'communication between staff members', 'early consultant review', 'flexibility by future expansion', 'patient flow' and 'flexible nurse staffing'. The hierarchy that is built is shown in Figure 17.

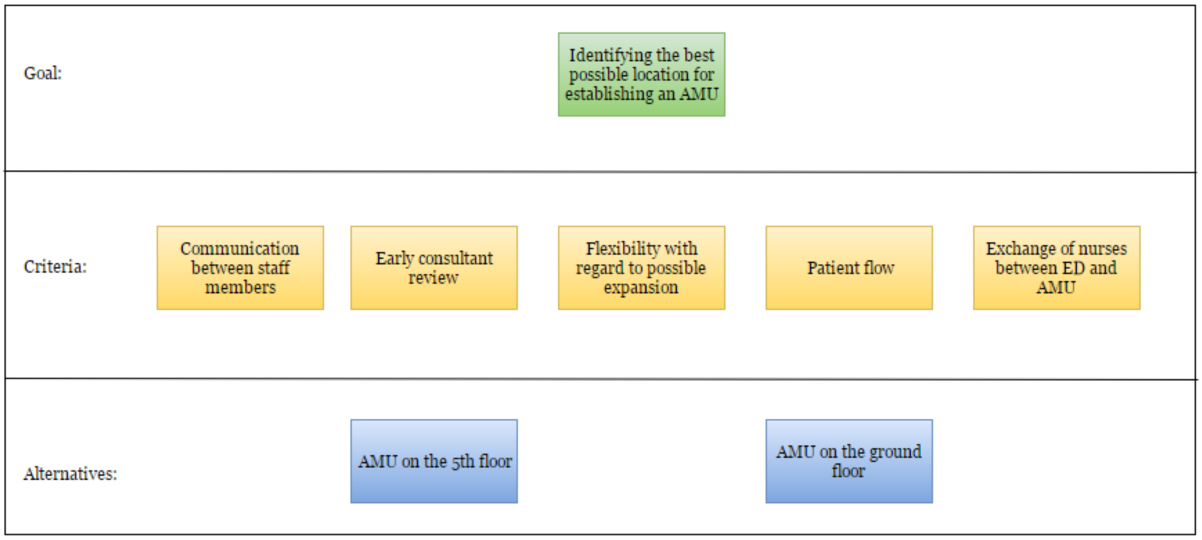


Figure 17 - Hierarchy of the AHP analysis

Good communication between staff members

Good communication between nurses of the ED and AMU is an essential condition to ensure the continuity of care. A patient crosses a variety of disciplines in the acute phase of hospital admission. The collaboration is highly dependent on the exchange of patient information during different care processes such as the patient transportation from the ED to the AMU. By consistent communication between nurses, doctors and care assistants, a common platform arises from which interventions starts who determine the patient outcomes and the continuity of care. If healthcare professionals are not communicating effectively, patient safety will be at risk. Collaboration between physicians, nurses, and other health care professionals increases team members' awareness of each others' type of knowledge and skills, leading to continued improvement in decision making.

Timely consultant review

Timely consultant review (and decide on the subsequent treatment program) is the way to optimize the patient throughput at the AMU. It is important that all physicians will undertake ward rounds twice a day on their own patients at the AMU. These consultants start early in the morning, before the visits of physicians at the regular wards. Each physician will review their own patients. After those visits at the AMU, the required investigations, dismissal or transportation to the medical wards or home will be put in motion. Patients stay at the AMU for a maximum of 48 hours. That makes it imperative that the physicians review at least twice a day their patients at the AMU in order to agree on the policies to be followed by the nurses at the AMU. In this way, patients should not unnecessarily keep occupy a bed. In practice, some physicians often fail to arrive on time to review their patients.

Flexibility with regard to future expansion

Possible expansion is an important aspect by establishing an AMU. Many hospitals have seen a substantial rise in emergency admissions and this will probably continue to rise. There must therefore be sufficient opportunities to expand the AMU in the future if necessary.

Patient flow

Optimizing patient flows as efficiently as possible is one of the priorities in many hospitals. Optimized patient flows can lead to improved quality of care and waits, delays and cancellations may be reduced. Optimized patient flows can be achieved by placing the necessary departments close together.

Exchange of nurses between ED and AMU

A growing number of hospitals have the intention to use flexible staffing across different departments in order to achieve efficiency advantages. The degree of variability in the number of patients in a department is in important aspect in order to quantify the potential of flexible nurse staffing. Departments who are faced with a high degree of variability greatly benefit from working with a model of flexibility to achieve efficient nurse staffing. With the exchange of nurses between the ED and the AMU by providing support functions, an increased patient throughput can be realised.

Prioritise criteria

In the next phase we look at the preferences of the different decision makers with regard to the different criteria. The decision makers systematically evaluate the various criteria by comparing them to each other two at a time. Those pairwise comparisons are made in terms of importance on the basis of different numbers explained in Figure 20 in Appendix G. The comparisons of the criteria from the various decision makers and the values that arises from these comparisons are displayed in matrices and shown in Table 35 in Appendix G2.

The priority value per criterion from each matrix is calculated using the mean of the normalized values. These values are displayed in the last column of each matrix in Table 36 in Appendix G3. This approach is based on three steps:

1. Sum of the elements of the column *j*
2. Normalization of the column *j*
3. Mean of row *i*

On the basis of the consolidated preferences of the different stakeholders, the priority vector of each criterion is calculated. Therefore, the mean of all priority values for each criterion is calculated and are shown in Figure 18.

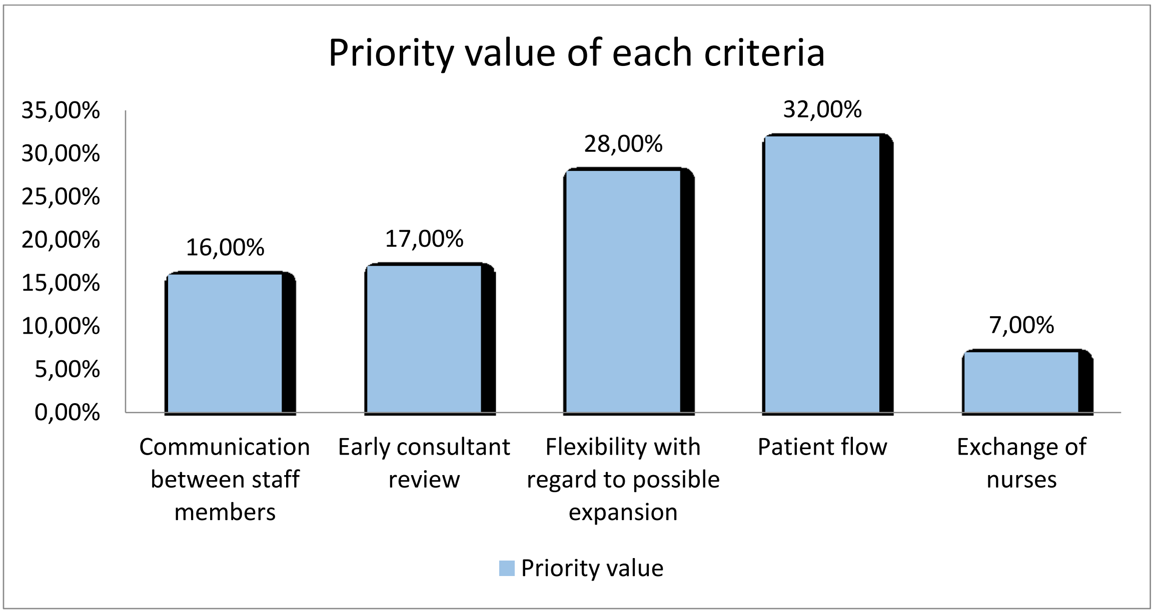


Figure 18 - Priority value of each criterion

The criteria 'flexibility with regard to possible expansion' and 'patient flow' have the highest values. 'Exchange of nurses between the ED and the AMU' has a relative low value. This is caused by the fact that participants see this aspect as an additional advantage but not necessary for an optimized process of the acute admissions. Early consultant review and the communication between staff members have approximately equal importance.

We calculated the consistency ratio (CR). The pair wise comparisons in a matrix are considered to be adequately consistent if the corresponding CR is less than 10%. In this case, the CR is 2.7%. The analysis is therefore consistent.

Prioritise alternatives

The preference of the alternatives with respect to each criterion is also determined by pairwise comparisons. There are two alternatives that need to be evaluated in terms of the five criteria: 'communication between staff members', 'early consultant review', 'flexibility with regard to possible expansion', 'patient flow' and 'exchange of nurses'. These pairwise comparisons are shown in Table 36 in Appendix G3.

The previous priority values of each criterion are used to form the entries of the decision matrix for this problem. Letv_{1} , v_2 , ... , v_5 denote the weights of the respectively criterion 1, 2, ..., 5 and p_{ij} $i = 1, 2, j = 1, 2, .., 5)$ the performance of the ith alternative on jth criterion. The global priority of both alternatives can be obtained as the weighted sum of performance:

$$w_i = \sum_{j=1}^{l} v_i \; p_{ij}$$

The next step is to choose between the alternatives, we combine the performance of the criteria with the preferences of the alternatives. The decision matrix and the resulted final priorities are shown in the Table 15. An AMU on the ground floor has the highest final priority with a score of 82%.

Table 15 - Final priorities of the AHP analysis

	v_1 (0.17)	v_2 *(0.17)*	v_3 *(0.29)*	v_4 *(0.29)*	v_5*(0.07)*	**Final Priority**
AMU on 5th floor $(i = 1)$	0.125	0.25	0.1	0.25	0.125	0.18
AMU on ground floor $(i = 2)$	0.875	0.75	0.9	0.75	0.875	0.82

5.3 Conclusions

In this chapter we presented the results of the experiments described in Section 4.5.1. We also presented the results of the AHP analysis. The costs of the different scenarios we examined are shown in Table 16 which are based on the average costs per year. We concluded that establishing an AMU on the on the ground floor minimizes the total transportation costs in each scenario.

Table 16 - Differences between the two interventions by means of costs

	Current data	*Current data incl. lung*	*Current data incl. lung + 10% growth*
AMU on 5th floor (€)	23,931	29,745	32,224
AMU on ground floor (€)	6,133	7,819	8,182
Δ in Euros (€)	17,798	21,923	24,042

The AHP analysis shows that the criteria ‘flexibility with regard to possible expansion’ and the ‘patient flow’ have the highest priority values. Exchange of nurses between the ED and the AMU has a relative low value. The resulted final priorities for both interventions are calculated and the situation in which the AMU is located near the ED on the ground floor has the highest final priority with a score of 82%.

In Chapter 6 we give the final conclusions and recommendations on our research.

6 Conclusion and recommendations

In this chapter, we present the conclusions of our research in Section 6.1. Recommendations will be discussed in Section 6.2 and we end this chapter with some suggestions for further research in Section 6.3.

6.1 Conclusions

This research was initiated since ZGT is considering establishing an AMU. ZGT management was looking for the way in which the acute admission process can be organized in the most efficient way and hence the following objective was established:

Gain insight in the both quantitative and qualitative differences of an AMU situated near to the emergency department, the current location of the outpatient rheumatology/ophthalmology, compared to an AMU situated on the 5th floor at the current ambulatory.

We defined several research questions to realize this objective, of which we present the answers short in this section.

The first question, *How is the current emergency admission process organized?*, is answered in Chapter 2. We identified the care path description of acute patients in the current situation. We saw that the ambulatory is used to take care of patients who are expected to be admitted for a short period of time. If there is no bed available or the patient has to be admitted for a longer period of time, the patient will be transferred to the (appropriate) medical ward. We identified the changes that occur when establishing an AMU. All acute patients who belong to the inclusion criteria will be transferred to the AMU for a maximum of 48 hours. After this period, patients will be discharged or transferred to a medical ward. We have analysed the expected arrival pattern at the AMU that will be used in the simulation model. The planning and control of acute patients and resources used in this process are identified.

From the literature we found previous research on the related subjects to answer the questions, *What is known in the literature about evidence of effectiveness and efficacy of AMUs, related facility layout problems and flexible nurse staffing?* From the literature we have seen that there is growing evidence for the efficacy and effectiveness of AMUs. AMUs reduce all-cause hospital mortality, length of stay of acute patients and ED waiting times. Direct discharge rate will be increased. We found several articles focus on approaches for solving facility layout problems in order to make layouts more efficient by taking into account various interactions between facilities and discusses the integrated approaches that feature both the quantitative and qualitative aspects of such a problem. In our research, we choose to use a simulation model to evaluate the quantitative measures and the qualitative criteria will be evaluated by AHP to determine the weight of qualitative measures.

To answer the question, *How can we model the acute admission process?*, we described the conceptual model for the acute admission process when establishing an AMU. The expected arrival rates based on historical data is used as input for the arrival rates at the AMU in the simulation model according to a Poisson distribution. The probabilities for the need for an OR or diagnostic services are investigated and used as input in the simulation model. We measured the distribution of the transportation times for each distance to the ED, the ORs and the diagnostic department. We defined the two interventions and three scenarios we used, the first based on the current arrivals, the second based on the current arrivals including lung diseases and the third based on the second plus a grow of 10% in the arrival rate.

The answer to the question *What are the results of the executing experiments?*, is given in Chapter 5. We combined the quantitative measures resulted from the output of the simulation model and the qualitative measures resulted from the AHP analysis. We found that the total transportation costs in the intervention in which the AMU is located on the ground floor has always the lowest costs in each scenario. From the AHP analysis we concluded that the situation in which the AMU is located on the ground has a significantly higher final priority with a score of 82%.

To answer the final question, *What is the conclusion of this study and what are the recommendations?*, we analyzed the results of the experiments we performed. We have seen that when the number of arrivals increases, the total transportation times increases and the difference between the two interventions will only increase. The qualitative measures are evaluated and have a significantly higher value for each criterion. An AMU on the ground floor offers both quantitative and qualitative benefits. Therefore, the costs of realizing an AMU on the ground floor should be weighed against both the quantitative as the qualitative advantages it provides if the AMU is located on the ground floor. The recommendations are discussed in Section 6.2.

6.2 Recommendations

In this section we provide the management of ZGT with recommendations on the implementation of the AMU.

When establishing an AMU, we recommend some important aspects in order to optimize the patient throughput at the AMU. The communication with the clinic admission office has to be intensive. The clinic admission office has good insight in the number of patients at the AMU at each time of the day and the number of patients that will be discharged on that day, either to the medical ward or home. Also the communication with the transfer office is of great importance. They must be very flexible in order to optimize the throughput of the patients and ensure that patients can leave the hospital if there is no need any more for hospitalization. The pharmacy also plays an important role in the throughput of patients at the AMU. The communication with the pharmacy is important. The pharmacy medication lists of the concerned patients should timely be mapped. If this takes too long it can cause unnecessary delays.

As resulted from the AHP analysis, early physicians review is very important for optimizing the patient throughput at the AMU. Physicians have to undertake ward rounds twice a day on their own patients at the AMU on the proposed times. If the physicians fail to arrive on time at the AMU, patients will unnecessarily keep occupy a bed and the required investigations will be delayed.

We recommend on having a review board to have insight in the presented patients at the AMU and the length of stay of these patients. In this way, medical staff has insight in the number of patients that will leave the AMU in a given time interval.

6.3 Further research

In this section we present possibilities for further research in order to coordinate the acute patient flow as efficient as possible.

In this research we mapped both the quantitative and qualitative differences between the locations of an AMU. As mentioned in Section 6.1, we recommend on doing further research on weighting the costs of establishing an AMU on the ground floor against the quantitative and qualitative benefits of an AMU located on the ground floor according to this research in the long term.

In order to make efficient use of nurses at both the ED and the AMU, we recommend identifying how often supportive tasks at the ED are necessary. These supportive tasks could be carried out by nurses from the AMU. We recommend on doing research on developing optimal staffing levels by making use of float nurses that are enabled to float between the ED and the AMU.

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Appendices

Appendix A - Arrival distributions

A1 - Arrival distributions at the ED

Table 18 - P-values two-sample t-test for all days of the week

Day of the week	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Monday	0.00*	0.00*	0.00*	0.93	0.00*	0.00*
Tuesday	-	0.75	0.10	0.00*	0.80	0.01*
Wednesday	-	-	0.20	0.00*	0.96	0.00*
Thursday	-	-	-	0.00*	0.20	0.00*
Friday	-	-	-	-	0.00*	0.00*
Saturday	-	-	-	-	-	0.01*

*Significant difference with α = 0.05

Table 19 – Underlying distributions for each day

Day of the week	Distribution	P1	P2
Monday	Normal	69.44	9.60
Tuesday	Normal	59.48	8.80
Wednesday	Normal	60.06	9.49
Thursday	Normal	62.47	9.72
Friday	Logistic	68.66	5.83
Saturday	Lognormal	59.96	10.12
Sunday	Lognormal	54.79	8.53

Normal/Lognormal: P1 = mean, P2 = standard deviation; Logistic: P1 = mean, P2 = scale

Table 20 - Outcome distributions of the Anderson Darling test for all days of the week at the ED

	Mon		Tue		Wed		Thu		Fri		Sat		Sun	
	P	AD	P	AD	P	AD	P	AD	P	AD	P	AD	P	AD
Normal	0.332	0.410	0.527	0.318	0.281	0.440	0.839	0.215	0.006	1.125	0.038	0.790	0.295	0.431
Lognormal	0.104	0.615	0.316	0.395	0.068	0.688	0.117	0.594	0.019	0.910	0.265	0.450	0.376	0.387
Logistic	0.250	0.317	>0.250	0.336	>0.250	0.351	>0.250	0.155	0.022	0.796	0.114	0.548	0.177	0.490
Exponential	<0.003	18.005	<0.003	17.540	<0.003	17.300	<0.003	17.559	<0.003	17.478	<0.003	16.977	<0.003	17.276
Weibull	0.084	0.657	0.158	0.559	0.042	0.773	>0.250	0.229	<0.010	1.798	<0.010	1.430	0.057	0.720
Gamma	0.210	0.513	>0.250	0.342	0.163	0.563	>0.250	0.421	0.020	0.927	0.205	0.529	>0.250	0.369

Table 21 - Outcome of the Anderson Darling test on the number of arrivals per week at the ED

	P	AD
Normal	0.218	0.485
Lognormal	0.071	0.680
Logistic	>0.250	0.393
Exponential	<0.003	20.297
Weibull	0.227	0.485
Gamma	0.128	0.601

A2 - Arrival distributions at the AMU

Table 22 – P-values two-sample t-test for all days of the week

	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Monday	0.00*	0.00*	0.00*	0.12	0.00*	0.00*
Tuesday	-	0.25	0.42	0.00*	0.55	0.76
Wednesday	-	-	0.68	0.00*	0.53	0.37
Thursday	-	-	-	0.00*	0.83	0.60
Friday	-	-	-	-	0.00*	0.00*
Saturday	-	-	-	-	-	0.76

*Significant difference with α = 0,05

Table 23 - Underlying distributions for each day

Day of the week	Distribution	Mean	Standard deviation
Monday	Normal	17.48	4.09
Tuesday	Gamma	9.24	1.58
Wednesday	Gamma	9.16	1.51
Thursday	Normal	14.09	4.13
Friday	Normal	16.59	4.19
Saturday	Logistic	14.21	4.18
Sunday	Normal	14.39	4.37

Normal: P1 = mean, P2 = standard deviation; Logistic: P1 = mean, P2 = scale; Gamma: P1 = shape, P2 = scale

Table 24 - Outcome Minitab distributions for all days of the week at the AMU

	Mon		**Tue**		**Wed**		**Thu**		**Fri**		**Sat**		**Sun**	
	P	AD	P	AD	P	AD	P	AD	P	AD	P	AD	P	AD
Normal	0.163	0.539	0.006	1.108	0.054	0.733	0.126	0.583	0.303	0.430	0.025	0.871	0.306	0.428
Lognormal	0.018	0.922	0.065	0.703	0.098	0.630	<0.005	1.430	0.007	1.095	<0.005	1.587	0.012	0.997
Logistic	0.057	0.644	0.010	0.908	0.017	0.843	0.059	0.642	0.154	0.512	0.067	0.626	0.095	0.571
Exponential	<0.003	28.308	<0.003	22.380	<0.003	22.325	<0.003	24.210	<0.003	26.946	<0.003	24.584	<0.003	23.084
Weibull	0.073	0.688	<0.010	1.137	0.083	0.666	0.109	0.615	0.222	0.494	<0.010	1.128	>0.250	0.400
Gamma	0.085	0.668	0.180	0.547	>0.250	0.440	0.022	0.910	0.062	0.725	0.015	0.981	0.119	0.612

Table 25 - Outcome of the Anderson Darling test on the number of arrivals per week at the AMU

	P	AD
Normal	0.535	0.314
Lognormal	0.491	0.338
Logistic	>0.250	0.418
Exponential	<0.003	20.595
Weibull	0.230	0.482
Gamma	>0.250	0.341

Appendix B - Probabilities of surgeries and diagnostic tests

Table 26- Probability of diagnostic tests per specialty

	P
OPHTHALMOLOGY	22.58%
INTERNAL SURGERY	74.02%
SURGERY	69.87%
GASTROENTEROLOGY	80.48%
THROAT-, NOSE- AND OTOLOGY	39.22%
ORAL PATHOLOGY AND DENTAL SURGERY	28.38%
PLASTIC SURGERY	49.42%
ANESTHESIOLOGY	78.38%
DERMATOLOGY	47.73%
RHEUMATOLOGY	69.05%
UROLOGY	46.53%

Table 27 - Probability of surgeries per specialty

	PROBABILITY
OPHTHALMOLOGY	9.44%
ANESTHESIOLOGY	29.73%
SURGERY	28.43%
DERMATOLOGY	25.00%
GASTRO-ENTEROLOGY	24.58%
INTERNAL SURGERY	19.55%
THROAT-, NOSE- AND OTOLOGY	32.11%
ORAL PATHOLOGY AND DENTAL SURGERY	28.38%
PLASTIC SURGERY	47.47%
RHEUMATOLOGY	14.29%
UROLOGY	46.53%

Appendix C – Search strategy

In this section, the methodology of conducting the literature review is described. Academic refereed journal articles are used in constructing the theoretical framework. Different data bases were used, like Web of Science, Scopus, Pubmed and Google Scholar. Furthermore, scientific books were used. The date of publishing is used to determine whether an article is relevant for our research. Articles published between 1990 and 2016 are included since the number of published articles is significantly increased since 1990. Another inclusion criteria was language, we only used articles in English and Dutch. Additionally, articles were sorted on relevance.

To generate combinations of the search terms, operators like AND, OR and an asterisk are used. Based on the combinations of search terms a set of articles were found. From the relevant articles found, the title and abstract are read to determine whether an article is relevant for our research. The title and abstract were read to determine whether an article is relevant for our research. If an article is considered to be relevant, the whole article is read. If not, the article is discarded. For the selected articles we looked into citations to determine other relevant articles that were not found based on the search terms in the initial search.

The terms that are used can be found in the Table 28.

Table 28 - Search terms used in literature

Search term	Related terms	Narrower
Acute medical unit	Acute assessment unit, acute medical assessment unit, medical assessment and planning unit, acute medical wards, early assessment medical units	Objectives Benefits
Effectiveness AMU	Effectiveness Efficacy	Key performance indicators
Process	Function Design Characteristics	Design characteristics Operational characteristics Patient flow
Location Acute Medical Unit	Facility layout Hospital design	Minimize travel times, transportation times,

	Locating facility Locating department	transportation costs Hospital design
Solving facility layout problems	Approach facility layout problems	Integrated approach solving facility layout problems Simulation AHP Quantitative and qualitative
Flexible nurse staffing	Exchange of personnel Exchange of nurses Flexible staffing Cross-utilization	Nurses Hospital

Appendix D - Input simulation model

D1 Arrivals at the AMU

Table 29 - Input parameters for arrivals at the AMU

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
1:00	0.69	0.69	0.69	0,64	0.81	1.12	0.94
2:00	0.60	0.50	0.38	0.49	0.35	0.60	0.67
3:00	0.44	0.25	0.33	0.26	0.46	0.52	0.50
4:00	0.15	0.33	0.27	0.21	0.35	0.56	0.40
5:00	0.37	0.29	0.31	0.32	0.17	0.37	0.37
6:00	0.19	0.21	0.21	0.13	0.13	0.25	0.38
7:00	0.25	0.19	0.12	0.09	0.23	0.31	0.23
8:00	0.06	0.08	0.08	0.21	0.06	0.23	0.25
9:00	0.21	0.02	0.06	0.11	0.25	0.21	0.23
10:00	0.29	0.08	0.19	0.19	0.17	0.23	0.21
11:00	0.38	0.42	0.50	0.38	0.52	0.52	0.62
12:00	0.65	0.75	0.77	0.62	0.77	0.79	0.52
13:00	1.19	0.77	0.81	0.92	1.02	1.04	0.60
14:00	1.12	0.81	0.96	0.75	1.17	0.94	0.83
15:00	1.63	1.17	1.04	1.09	1.54	0.96	0.94
16:00	1.44	1.04	1.12	1.23	1.23	1.02	0.94
17:00	1.60	1.15	1.69	1.08	1.56	1.00	0.88
18:00	1.56	1.04	1.21	1.34	1.56	1.21	0.94
19:00	1.58	1.19	1.10	1.09	1.23	0.81	0.65
20:00	1.38	1.06	0.81	1.08	1.29	0.94	0.79
21:00	0.87	1.15	0.90	1.02	1.02	1.04	0.77
22:00	0.90	0.83	0.83	0.74	0.81	0.58	0.88
23:00	0.77	0.88	0.63	1.02	0.94	0.96	0.88
0:00	0.81	0.67	0.54	0.45	0.73	0.81	0.77

Table 30 - Week factors for each week

Week number	Week factor	Week number	Week factor
1	1.06	27	1.02
2	1.15	28	1.11
3	0.95	29	1.02
4	0.89	30	0.92
5	1.04	31	0.99
6	0.95	32	0.93
7	0.89	33	1.02
8	0.76	34	0.92
9	0.87	35	1.02
10	0.98	36	1.10
11	1.10	37	1.08
12	0.76	38	0.98
13	1.00	39	1.09
14	1.06	40	1.01
15	1.06	41	0.92
16	1.09	42	1.02
17	1.04	43	1.03
18	1.09	44	1.05
19	0.95	45	0.95
20	0.94	46	1.02
21	1.07	47	1.08
22	0.88	48	1.08
23	0.96	49	0.93
24	1.03	50	1.09
25	0.88	51	1.10
26	0.96	52	0.87

Table 31 - Length of stay distributions for patients at the AMU

Length of stay (hr)	Probability	Length of stay (hr)	Probability
0:00:00	0,00%	26:00:00	2,19%
2:00:00	0,36%	28:00:00	1,07%
4:00:00	0,58%	30:00:00	0,66%
6:00:00	1,22%	32:00:00	0,65%
8:00:00	1,46%	34:00:00	0,75%
10:00:00	1,65%	36:00:00	0,95%
12:00:00	1,90%	38:00:00	1,04%
14:00:00	1,87%	40:00:00	1,31%
16:00:00	1,85%	42:00:00	1,72%
18:00:00	2,35%	44:00:00	1,87%
20:00:00	2,65%	46:00:00	1,41%
22:00:00	2,30%	48:00:00	65,49%
24:00:00	2,69%		

Appendix E – Reliable point estimates for the simulation model

In this appendix we determine a warm-up period for the simulation model (E1). We also decide on how many replications to execute in order to obtain reliable point estimates (E2).

E1 – Warm-up period

In this study we have a non-terminating simulation and we are interested in the long term behaviour of the system. To determine the warm-up period, we use the graphical method of Welch. Welch's procedure is based on making *n* independent replications of the simulations and employing the following four steps:

1. We make *5* replications of the simulation, each of length 1 year
2. We calculate the mean of the i^{th} observation over all 5 replications
3. We calculate the moving average with a window of 500, 1000, 2000, to smooth out the high-frequency oscillations
4. We plot the moving averages and choose observation *l* beyond which the output seems to be converged

The results of the graphical method of Welch are shown in Figure 19 Only the first three months are shown in the figure. From this figure we see that the system is already in a steady state after 636 time slots, which equals 26.5 days. From this point, the system is in steady-state.

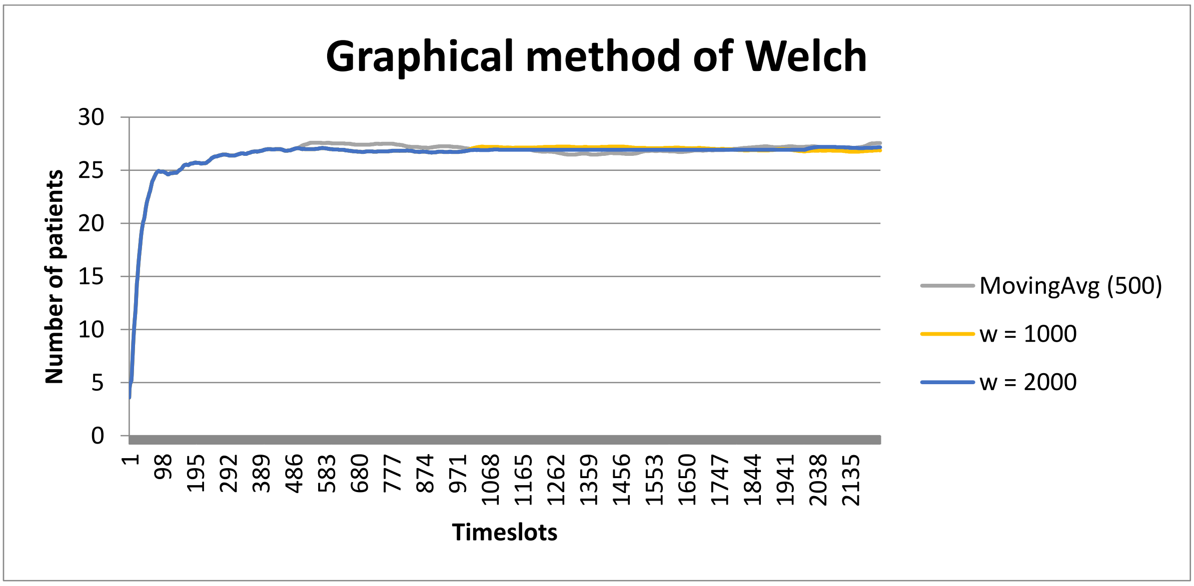

Figure 19 - Graphical method of Welch, 5 replications of 1 year.

E2 – Number of replications

We need to determine the number of replications required to make sure that the confidence intervals for the outcome measures of the simulation model do not get too wide. According to Law (2007), the length of m needs to be much larger than the warm-up period. We therefore choose a run length of 1 year.

To make sure the confidence interval of our outcomes is not too large, we have to determine the smallest number of replications required such that:

$$\frac{t_{n-1,1-\alpha/2}\sqrt{S_n^2/n}}{\bar{X}_n} \leq \gamma'.$$

We compute the average (X_n) of the *n* replications, the variance (S_n^2) in the *n* replications. $t_{n-1,1-a/2}$ is the student t-value for $(n-1)$ degrees. We use a confidence interval of $(1-\alpha)$ and is $\gamma'$the relative error and is calculated by$\frac{y}{1+y}$. We use a 95% confidence interval and a relative error of 0.10.

We investigated the required number of replications for number of patients at the AMU such that the half width of the 95% confidence interval is not bigger than γ'. The number of replications needed for this measure is shown in Table 32. This table shows a small part of the calculations. By executing 2 experiments, $n*$ is smaller than y'.

Table 32: Number of replications needed

N (run)	*Mean*	*Cum. Mean*	*Variance*	*t.inv*		$n*$	$<y'$
1	26.97	26.97	-	-	-		
2	27.47	27.22	0.06	12.71	2.25	0.08	Yes

Summarizing, we execute 2 replications and each replication has a run length of one year.

Appendix F – Costs and FTEs

In Table 33 we see that each contracted nurse is available for a total of 1540 hours per year.

Table 33 - Gross hours and net hours per year per FTE

Work hours per week	36 hours
Number of weeks per year	52,18 weeks
Gross hours per year	**1878.43 hours**
Reduction for vacation days and sick leave	-338,43 hours
Net hours per year	**1540 hours**

The function of a nurse is classified into one of the function classes 5-80, which is done according the FWG-system. The function class determines the salary scale. General nurses get a salary according to scale 45, while specialist nurses get salaries according to scale 50. Within each salary scale one can earn more as the years of experience becomes bigger. The salaries for each class can be seen in Table 34. For the average amount of salary for a general nurse, ZGT uses the level 45-10, which means scale 45 with ten years experience. For the specialist nurse, we use the level 55-10. We see that a general nurse earns on average €2,829.00 per month, which is a total of €33,948.00 per year. A specialist nurse earns on average €3,227.00 per month which is a total of €38,724.00.

Nurse assistants get salaries according to scale 30. The salaries for each class can be seen in Table 34. For the average amount of salary for a nurse-assistant, ZGT uses level 30-10. We see that a nurse assistant earns on average €2,378.00 per month, which is a total of €28,536.00.

General nurses and specialist nurses may both be responsible for the transport of patients. We made the assumption that they are both responsible for half of the transportation times. Therefore we calculated the average year salary of a general nurse and a specialist nurse which is a total of €36,336.00. Nurse assistants are responsible for transport to function departments like radiology. Therefore we calculated the average year salary of a nurse assistant which is a total of €28,536.00.

Table 34 - Salaries for scale 30, 45 and 50

Experience (years)	***Scale 30*** *ip-number*	*Salary (€)*	***Scale 45*** *ip-number*	*Salary (€)*	***Scale 50*** *ip-number*	*Salary (€)*
0	6	1640	14	2066	17	2251
1	8	1727	16	2195	19	2378
2	10	1821	18	2317	21	2505
3	12	1935	19	2378	23	2631
4	13	2000	20	2442	25	2760

5	14	2066	21	2505	27	2898
6	15	2126	22	2567	28	2960
7	16	2195	23	2631	29	3029
8	17	2251	24	2695	30	3097
9	18	2317	25	2760	31	3162
10	19	2378	26	2829	32	3227
11	20	2442	27	2898	33	3294
12			28	2960	34	3363

Appendix G – AHP analysis

G1 - Prioritization numbers

The Fundamental Scale for Pairwise Comparisons		
Intensity of Importance	**Definition**	**Explanation**
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one element over another
5	Strong importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another; its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
Intensities of 2, 4, 6, and 8 can be used to express intermediate values. Intensities 1.1, 1.2, 1.3, etc. can be used for elements that are very close in importance.		

Figure 20 - Prioritization numbers

G2 - Comparing criteria

There are 5 criteria that need to be compared on the basis of the pair wise comparisons. The following matrices represent the corresponding judgment matrices with the pair wise comparisons. The corresponding priority vectors are given as well. To calculate the priority vector we perform the following steps:

1. We sum each column of the reciprocal matrix
2. We divide each element of the matrix with the sum of its column, and then we have the normalized relative weight. The sum of each column is 1.
3. The normalized principal priority vector is obtained by averaging across the rows

Table 35 - Comparison matrices filled in by policy advisor, unithead of the ambulatory, nurses at the ambulatory and the unit head of the ED

	1	2	3	4	5	Priority value
1	**1**	3	1/5	1/5	3	0.14
2	1/3	**1**	1/3	1/3	3	0.11
3	5	3	**1**	1	7	0.37
4	5	3	1	**1**	5	0.34
5	1/3	1/3	1/7	1/5	**1**	**0.05**

	1	2	3	4	5	Priority value
1	**1**	1	1/5	1	5	0.16
2	1	**1**	1/3	1	3	0.15
3	5	3	**1**	3	5	0.46
4	1	1	1/3	**1**	5	0.17
5	1/5	1/3	1/5	1/5	**1**	**0.05**

	1	2	3	4	5	Priority value
1	**1**	1/2	3	1/4	1	0.13
2	2	**1**	3	1/3	5	0.25
3	1/3	1/3	**1**	1/3	1/3	0.07
4	4	3	3	**1**	5	0.44
5	1	1/5	3	1/5	**1**	**0.11**

	1	2	3	4	5	Priority value
1	**1**	1/2	3	1/4	1	0.13
2	2	**1**	3	1/3	5	0.25
3	1/3	1/3	**1**	1/3	1/3	0.07
4	4	3	3	**1**	5	0.44
5	1	1/5	3	1/5	**1**	**0.11**

	1	2	3	4	5	Priority value
1	**1**	1	1/3	4	5	0.25
2	1	**1**	1/5	1/3	5	0.13
3	3	5	**1**	1	5	0.36
4	1/4	3	1	**1**	3	0.20
5	1/5	1/5	1/5	1/3	**1**	**0.05**

	1	2	3	4	5	Priority value
1	**1**	3	1/5	1/5	3	0.14
2	1/3	**1**	1/3	1/3	3	0.11
3	5	3	**1**	1	7	0.37
4	5	3	1	**1**	5	0.34
5	1/3	1/3	1/7	1/5	**1**	**0.05**

G3 - Comparing alternatives

There are two alternatives that need to be evaluated in terms of the five decision criteria: 'communication between staff members', 'early consultant review', 'flexibility with regard to possible expansion', 'patient flow' and 'exchange of nurses'. The pair wise comparisons with respect to each criterion are shown in the matrices below. We follow the same three steps as in Appendix G2 to calculate the priority vector.

Table 36 - Pairwise comparison matrix with respect to each criterion

C1: Communication between staff members	*AMU on 5th floor*	*AMU on ground floor*	*Priority vector*
AMU on 5th floor	1	1/7	1/8
AMU on ground floor	7	1	7/8

C2: Early consultant review	*AMU on 5th floor*	*AMU on ground floor*	*Priority vector*
AMU on 5th floor	1	1/3	1/4
AMU on ground floor	3	1	3/4

C3: Flexibility (possible expansion)	*AMU on 5th floor*	*AMU on ground floor*	*Priority vector*
AMU on 5th floor	1	1/9	1/10
AMU on ground floor	9	1	9/10

C4: Patient flow	*AMU on 5th floor*	*AMU on ground floor*	*Priority vector*
AMU on 5th floor	1	1/3	1/4
AMU on ground floor	3	1	3/4

C5: Exchange of nurses between ED and AMU	*AMU on 5th floor*	*AMU on ground floor*	*Priority vector*
AMU on 5th floor	1	1/7	1/8
AMU on ground floor	7	1	7/8

The previous priority vectors are used to form the entries of the decision matrix for this problem. The decision matrix and the resulted final priorities are shown in the matrix below.

	C_1 (0,17)	C_2 (0,17)	C_3 (0,29)	C_4 (0,29)	C_5(0.07)	**Final Priority**
AMU on 5th floor	0,125	0,25	0,1	0,25	0,125	0,17
AMU on ground floor	0,875	0,75	0,9	0,75	0,875	0,82