MODELING AN INTEGRATED EMERGENCY POST

Designing a simulation model for the collaboration between the GP post Almelo and the emergency department of ZGT Almelo

R.E. Visser

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Management Summary

In April 2010, the Integrated Emergency Post (IEP) Almelo was opened. This is a collaboration between the General Practitioners post (GP post) Almelo and the emergency department (ED) of ZGT Almelo. To be able to benefit the most from this collaboration, for example by increasing cost efficiency and quality of service, a research project was started in April 2011. The goal of the research project is to form a scientific foundation on how to reach an optimal process design for the integrated emergency post, in which the correct patient is provided with the right care by the correct caregiver, with optimal use of resources and without unnecessary delays, while taking patient preferences into account *(Doggen, Hans, Snel, Velde, & Verheij, 2010)*. To reach this goal, several organizational interventions need to be tested and their results need to be analyzed. The testing of these interventions will be done using a simulation model.

The study described in this thesis is part of the research project and concerns the design phase of the simulation model. The goal of this study is *to design the conceptual model of the IEP, to determine the input data for the simulation model, and to verify and validate the final simulation model.* To do this, we start with describing the way the IEP works. To model the processes, we have to make assumptions, for example with respect to the variables that determine the route a patient takes through the IEP and the relationships between these variables. Subsequently, these assumptions are tested by performing a data analysis of historic data from the GP post and the ED. This historical data also forms the basis for determining the input data for the simulation model. The collection of assumptions, together with the gathered input data, forms the conceptual model. This conceptual model is translated directly into the computer simulation model.

When the simulation model is finished, it needs to be verified and validated in order to establish credibility. For this verification and validation various techniques, as described by Law (2007) were used. The verification focuses on to what extend the translation from conceptual to simulation model was done correctly. The validation step is to compare the simulation model and its outcomes to the real world situation.

From the verification, we conclude that there are still some errors in the computer simulation model, for example regarding the reviewing of results from diagnostic tests at the ED. To get a more reliable and realistic model, extra improvement iterations must be performed to solve these issues. To compare the simulation model and its outcomes to reality we used some quantitative as well as qualitative techniques. We performed a data analysis on the distribution of arrivals. The conclusion from this analysis was that the input settings did not form a perfect fit to the historical data. Therefore some improvement iterations were performed, which lead to new settings for the arrival distributions. We also did an analysis of the model outcomes with respect to waiting times for the different processing steps at the IEP. These outcomes seem to be realistic. Some of the qualitative validation techniques used were, among others, discussing the assumptions with involved stakeholders and watching the animation of the simulation model to check for particularities. There were some strange events seen in the model that would not occur in reality, such as a situation in which all general practitioners leave the GP post at the same time for visits, or patients having to wait at home for three hours for a consultation, while there are no other patients at the IEP.

Overall, the current simulation model is a good start, but needs to be developed further before it is possible to test interventions and get reliable results. Some aspects of the conceptual model need to be redesigned in order to get a better representation of reality. Also, more research has to be done to get more reliable input data, for example regarding the processing times per task at the IEP. When the model is improved and more extensively validated with the involved stakeholders, the model can be used to test interventions.

Samenvatting

In april 2010 is de Spoedpost Almelo geopend. Dit is een samenwerkingsverband tussen de Centrale Huisartsenpost Almelo en de spoedeisende hulp afdeling van Ziekenhuisgroep Twente in Almelo. Om zoveel mogelijk voordeel uit deze samenwerking te behalen, bijvoorbeeld door het verhogen van kostefficiëntie en de kwaliteit van de zorg, is er een onderzoeksproject gestart in april 2011. Het doel van dit project is het vormen van een wetenschappelijke basis voor het "komen tot de optimale inrichting van een spoedpost waarbij de juiste patiënt zonder onnodige vertraging met een optimale inzet van middelen bij de juiste zorgverlener terecht komt, waarbij ook rekening wordt gehouden met de waardering die de patiënt aan allerlei factoren in dit acute zorgproces geeft" *(Doggen, Hans, Snel, Velde, & Verheij, 2010)*. Om dit te bereiken worden diverse organisatie interventies getest en hun resultaten geanalyseerd. Het testen van deze interventies zal worden gedaan met behulp van een simulatiemodel.

Het onderzoek dat in dit verslag wordt beschreven maakt deel uit van het onderzoeksproject en heeft betrekking op het ontwerpen van het simulatiemodel. Het doel van dit deelonderzoek is het ontwerpen van het conceptuele model van de spoedpost, het vaststellen van de inputdata voor het simulatiemodel, en het verifiëren en valideren van het uiteindelijke simulatiemodel. Hiervoor beginnen we met het beschrijven van de werking van de spoedpost. Om de processen van de spoedpost te modeleren, is het nodig om aannames te doen, bijvoorbeeld met betrekking tot de variabelen die invloed uitoefenen op welke route een patiënt door de spoedpost volgt en de onderlinge relaties tussen die variabelen. Vervolgens zullen deze aannames getest worden door middel van een data-analyse van historische data van de huisartsenpost en de spoedeisende hulp afdeling. Deze historische data vormt ook de basis voor het vaststellen van de inputdata voor het simulatiemodel. De verzameling aannames vormt samen met de verzamelde inputdata het conceptuele model. Dit conceptuele model wordt rechtstreeks vertaald naar het computer simulatie model.

Wanneer het simulatiemodel geprogrammeerd is, moet het worden geverifieerd en gevalideerd om geloofwaardigheid te verkrijgen. Hiervoor worden diverse technieken gebruikt die zijn beschreven door Law (2007). In de verificatie stap wordt er gefocust op de vraag in hoeverre de vertaling van het conceptuele model naar het simulatie model klopt. De validatie heeft betrekking op de vergelijking tussen het simulatie model en de werkelijkheid.

Vanuit de verificatiestap concluderen we dat er nog enkele fouten in het simulatie model zitten, bijvoorbeeld met betrekking tot het beoordelen van testresultaten van diagnostische testen die op de spoedeisende hulp worden uitgevoerd. Om een beter betrouwbaar en meer realistisch model te krijgen, moet er nog een verbeteringsslag worden uitgevoerd om deze fouten te verhelpen. Voor het vergelijken van het simulatiemodel met de werkelijkheid, zijn zowel kwantitatieve als kwalitatieve technieken gebruikt. Zo is er een data analyse uitgevoerd met betrekking tot de aankomstverdelingen. Hieruit bleek dat de resultaten van de gebruikte instellingen voor de verdelingen niet perfect overeenkwamen met de historische data. We hebben vervolgens enkele verbeteriteraties voor de instellingen uitgevoerd om tot betere resultaten te komen. Een andere validatie stap was het analyseren van de model uitkomsten met betrekking tot de wachttijden per processtap. Deze uitkomsten bleken vrij realistisch. Enkele van de gebruikte kwalitatieve validatie-technieken zijn het bespreken van de aannames met de betrokkenen uit de projectgroep, en het bestuderen van de animatie van het simulatiemodel om onregelmatigheden te ontdekken. Hieruit is een aantal vreemde zaken naar voren gekomen, zoals een situatie waarin alle huisartsen tegelijkertijd op visite gaan bij patiënten, of het feit dat patiënten soms uren thuis moeten wachten voor ze op consult mogen komen, terwijl er geen andere patiënten aanwezig zijn op de spoedpost.

Over het algemeen is het huidige simulatie model een goed begin, maar het model moet wel verder ontwikkeld en verbeterd worden, voordat het kan worden gebruikt om interventies te testen met betrouwbare testresultaten. Enkele aspecten van het conceptuele model moeten opnieuw worden ontworpen om een betere weergave van de werkelijkheid te krijgen. Ook moet er meer onderzoek worden gedaan om betrouwbaardere inputdata te verkrijgen, bijvoorbeeld met betrekking tot de procestijden van de activiteiten die op de spoedpost plaatsvinden. Wanneer het model verbeterd en uitgebreid gevalideerd is met de betrokken partijen, kan het worden gebruikt om interventies mee te testen.

Glossary

In the list below, we give an overview of the most common terms in this research, their synonyms and their translation.

- Integrated Emergency Post (IEP) = Spoedpost
- General Practitioners Post (GP post) = Huisartsenpost
- General Practitioner (GP) = Huisarts
- General Practitioners Assistant (GP Assistant), medical nurse = Doktersassistente
- Emergency Department (ED), Emergency and Accident Department (E&A) = Spoedeisende hulp afdeling
- ED Nurse = Spoedeisende hulp verpleegkundige
- Resident = Arts assistent
- Surgical Resident = Arts assistent chirurgie
- Medical Resident = Arts assistent interne geneeskunde
- Self-referral = Zelfverwijzer
- Surgical specialties = Snijdende specialismen
- Contemplative specialties = Beschouwende specialismen

Table of Contents

List of Tables and Figures

Preface

In May 2011, I started the internship for my master thesis at ZGT Almelo. In the same period I took the last course for my study and with writing this report, my 6,5 years of study came to an end. After the first year of new and exciting experiences, came two years of just taking courses. In my fourth year, when I had to do an internship for my bachelor thesis, I encountered the world of healthcare logistics. From that moment I knew which way I wanted to go with my studies. In the last two years I got more involved in the research that is done by the university in the field of healthcare. When it was time for me to search an internship for my master thesis, this research project in Almelo was proposed to me. Although I wasn't immediately excited about the assignment, my decision to 'just go for it', has definitely proved to be the right one.

For the past six months I really enjoyed working on this research project. Therefore I would like to thank the people of ZGT Almelo to give me the chance to do my thesis with them. Special thanks go to Manon Bruens, who has answered all of my questions to her, gave me lots of data and has been a great supervisor throughout this project. I also would like to thank the project members Janke Snel, from the GP post, Arlette Drost, Harry Verheij and Jaap Jongedijk from the ED, and Carine Doggen and Erwin Hans from the University of Twente, for giving feedback on all monthly discussion documents. Special thanks go out to Martijn Mes. I really enjoyed the combination of being supervised by you and at the same time working together on designing and constructing the simulation model. Also I would like to thank Ingrid Vliegen for her always constructive and honest feedback.

Not only within the project but also at home, I received nothing but support. Therefore, I like to thank Steven, for alternately motivating me and calming me down when needed. And last but definitely not least, I would like to thank my parents, for making it possible for me to study carefree and for supporting me all the way. I could not have done this without you!

I hope you will enjoy reading this report and that it will serve as a solid basis for the research still to come at the integrated emergency post of Almelo. I will continue to follow the research project and I am very curious for the achieved results, approximately 18 months from now.

Renske Visser
Enschede, December 2011

Chapter 1 Introduction

The study described in this thesis took place in Almelo, in one of the hospitals of 'Ziekenhuisgroep Twente' (ZGT). In April 2010 an integrated emergency post was opened. This is a partnership between the emergency department of the hospital and the general practitioner post. In the new situation, both services are located together in a new division of the hospital, which should stimulate effective patient care by the appropriate caregiver, a more efficient patient flow, and better use of resources.

This thesis originates from the ZonMW research project 'Optimale logistiek en patiënten voorkeuren in de acute zorgketen' (Optimal logistics and patient preferences in acute care), that examines how to improve the efficiency in operating an Integrated Emergency Post. The overall goal of the research is to reach an optimal process design for the integrated emergency post, in which the patient is provided with the right care by the correct caregiver with optimal use of resources and without unnecessary delays, while taking patient preferences into account *(Doggen, Hans, Snel, Velde, & Verheij, 2010)*. An important part of this research is to perform a simulation study, in which alternative organization interventions can be tested to reach the optimal process design. This thesis describes the translation from reality to simulation model and the analysis involved.

A simulation model is a powerful tool in finding possibilities for improvement since experimenting in real life is in most situations not possible. The first step in building a simulation model is to design a conceptual model *(Law, 2007)*. From this conceptual model, a computer simulation model is programmed. Emphasis in the design of the model lies on validating the conceptual model. This validation is meant to get support from the future users and involved actors and to establish credibility. This prevents situations in which actors disregard model outcomes, because they do not believe the model reflects reality. When the conceptual model is validated, it can be translated into a simulation model. When this simulation model is finished, a verification step is taken to check for translation and/or programming errors. To increase the credibility, the final simulation model is again validated. After the model is programmed and validated and approved by involved stakeholders, several scenarios will be tested and outcomes of these organizational interventions can be studied.

The objective of this study, as part of the larger research project, is to design the conceptual model of the IEP, to determine the input data for the simulation model, and to verify and validate the final simulation model. The main deliverables are (i) a validated conceptual model, (ii) a verified simulation model and (iii) a description of all assumptions made during the design phase. To reach this objective, first a description is given of the research area, the scope of the study and the research questions that are to be answered (Chapter 2). Then, a literature study is performed to learn more about the research subjects, such as simulation studies in general, general, simulation studies in healthcare and collaboration between GP posts and EDs (Chapter 3). After creating this basis, the conceptual model is designed. The conceptual model consists of a detailed description of reality and the translation to how this reality can be mimicked by the model (Chapter 4). The next step is to determine through data analysis which factors serve as the input factors and what the starting values of these factors should be (Chapter 5). After the data analysis, the conceptual model can be translated into a simulation model. This simulation model is then verified and validated and an overview is given of the shortcomings and pitfalls of the model, which should be taken into account by the future users of the model (Chapter 6). The results and conclusion of this study are given and we discuss some of the weaker points of this study (Chapter 7). This study ends with a description of the future work that lies ahead in the remaining part of the overall research project. Also a short account is given on possible ways in which the model can be improved to reach more resemblance to reality (Chapter 8).

Chapter 2 Project Framework

In this chapter, we give a short overview of the research project. This includes some facts on the hospital (2.1) and the general practitioners post (2.2) where the study takes place and an explanation of the workings of the integrated emergency post (2.3). After giving a description of the overall research project (2.4), we zoom in on the research design of this study (2.5), following the 7 steps of Verschuren & Doorewaard (2007).

2.1 ZGT Almelo

The hospital 'Ziekenhuisgroep Twente' (ZGT) is a general hospital with approximately 3500 employees and a service area of about 300.000 habitants. ZGT originated from a fusion of 'het Twenteborg Ziekenhuis' in Almelo and 'het Streekziekenhuis Midden-Twente' in Hengelo that took place in 1998 *(Ziekenhuisgroep Twente, 2011)*.

After the fusion, the hospital remained at the two locations in Almelo and Hengelo. At the site in Almelo, the integrated emergency post is located where this study takes place. Some key figures from 2009 and 2010 of ZGT are given in *Table 1.*

Table 1: Key figures ZGT 2009 and 2010, source: Ziekenhuisgroep Twente, 2011

	2009	*2010*
Turnover	€ 240.327.000	€255.661.584
Salaried Employees	3.683	3.699
Medical Specialists	211	207
Beds	1.085	1.085
Outpatient visits	548.239	599.038
Day admissions	46.725	47.142
Admissions	37.793	38.209
Nursing days	211.738	207.704

2.2. General Practitioners post Almelo

The General Practitioners post (GP post) of Almelo was founded to help people with an acute need for care at times that general practices are closed (outside regular office hours). The GP post provides medical care to approximately 203.000 inhabitants in the region Almelo *(CHPA)*. It employs 85 GPs, 35 specially trained GP assistants and 15 GP chauffeurs.

2.3 The Integrated Emergency Post

Outside of regular office hours, people with an acute need for care are often confused where to go. Although officially an emergency department (ED) of a hospital is secondary care, which means that patients should arrive there by referral, many patients do not treat it as such. They assess the seriousness of their demand of care and decide whether to go to a general practitioners post (GP post) or to the ED. At the ED these patients are called 'self-referrals'. In practice, many of the self-referrals could have been helped by a general practitioner (GP), but since they already are at the hospital, their need for care is satisfied at the ED. This leads to unnecessary overcrowding of the emergency department. On top of this, emergency care is more expensive than care by a general practitioner. Capacity and cost restrictions create a growing need to bring down the number of self-referrals at the emergency department *(Kool, Homberg, & Kamphuis, 2008)*. From this need, the idea was created for a gatekeeper function: healthcare professionals who decide for the patient where to go.

The Integrated Emergency Post (IEP) is a practical example of such a gatekeepers function. In this IEP, which was opened in April 2010, a GP post was build directly next to the new emergency department of the hospital of Almelo. A map of the new situation, with the main hall, the GP post and the ED, can be found in Appendix A.

In this new situation, people with acute need for healthcare (outside of regular office hours) can call the IEP. During the call, a GP assistant assesses the situation and decides what the best course of action is for the patient. She gives telephonic advice, sends a GP to the patient or asks the patient to come to the IEP for a consultation. The patients that used to go to the emergency department as self-referrals now enter the IEP through the main hall. There, a GP assistant examines the patient to determine the urgency of the situation. Then the GP assistant books the patient for a consult on the GP post, or directly refers the patient to the emergency department. This means that patients do not have to choose for themselves where to go and they do not arrive at the emergency department, unless a GP assistant or a GP refers them (Figure 1).

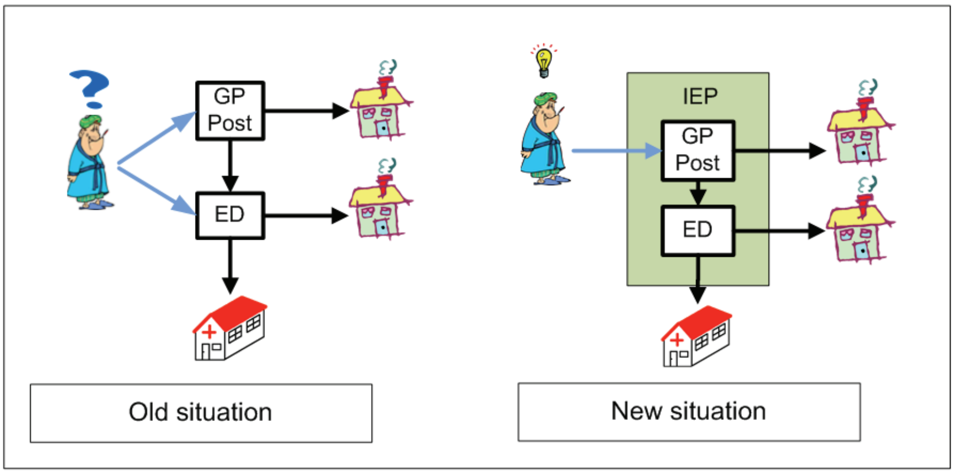

Figure 1: Patient choice before and after the opening of the IEP Almelo

2.4 The ZonMw Research Project

The research project 'Optimale logistiek en patiënten voorkeuren in de acute zorgketen' (Optimal logistics and patient preferences in acute care), in which this study takes place, is part of a ZonMw research program called 'Spoedzorg 2008' (Emergency Care 2008). ZonMw is an organization that finances healthcare research and stimulates the use of developed knowledge, to improve health and healthcare. The main clients of ZonMw are the ministry of Health, Welfare and Sports, and the Dutch Association for Scientific Research *(ZonMw, 2011)*. The participants of this project are ZGT, the 'Centrale Huisartsenpost Almelo' (CHPA, Central general practitioners post) and the University of Twente. The project is an implementation project that takes place in Almelo and started in April 2011. This means that the interventions with positive results from the simulation model will be implemented and tested in reality in the subsequent period.

One year before the start of the research project, in April 2010, the general practitioners post and the emergency department of the ZGT in Almelo were integrated in an Integrated Emergency Post (IEP). The goal of this integration is higher efficiency of care, because patients can be helped at the right place soon. Also higher efficiency is expected because of reduction in overlap between the two partners in organizing acute care and patient treatment. Furthermore there is the expectation of creating more clarity for patients, since only one window remains to turn to for acute care *(Doggen, Hans, Snel, Velde, & Verheij, 2010)*.

The goal of the project is to form a scientific foundation on how to reach an optimal process design for the integrated emergency post, in which the correct patient is provided without unnecessary delays by the correct caregiver with optimal use of resources, while taking patient preferences into account *(Doggen, Hans, Snel, Velde, & Verheij, 2010)*. The process design can, in this case, be optimized for example in terms of number and type of caregivers per time interval, the division of tasks, and the way in which patients flow through the IEP.

This goal leads to two groups of research questions of the research project as a whole *(Doggen, Hans, Snel, Velde, & Verheij, 2010)*:

1. What is the effect of the integration of the general practitioners post with the emergency department in Almelo on patient flow and throughput times for distinct groups of patient with distinct needs for healthcare? How do patients experience the factors that influence patient flows and throughput times, what value is attached to optimizing these factors and to which patient preference does this lead?

2. How can the process efficiency in the Integrated Emergency Post be optimized? Which organizational interventions does this lead to and how can these interventions be supported, implemented and evaluated?

As part of the overall ZonMw research project, this study aims at the second group of research questions, being on improving the process efficiency by implementing organizational and logistical interventions. However, optimizing the logistical structure of the IEP has consequences that are difficult to predict for the quality, costs and valuation of healthcare. To be able to experiment with possible organizational interventions without intervening in the real processes, part of the research exists of making a computer simulation model of the IEP of Almelo. With the simulation model that we design and build in this study, future studies can be done to analyze which interventions have positive results and should be implemented. In next section we look further into the design of this study on the modeling of the IEP.

2.5 Research Design

The first step in conducting any research is to think about the design of the research. A research design consists of two parts: a conceptual design and a technical design. The conceptual design describes what the goal of the research is, whereas the technical design describes how to reach this goal *(Verschuren & Doorewaard, 2007).*

2.5.1 The conceptual design

The conceptual design describes what, why and how much there is to be researched and consists of four parts: an objective, a research model, research questions, and the definition and operationalization of the main concepts *(Verschuren & Doorewaard, 2007)*.

The objective of a study describes what is to be gained from the study or why it is being performed. To reach the objective, certain steps need to be taken. A research model is a schematic overview of these steps and the interrelationships between different parts of the research. The research model also helps to identify the main research questions and sub questions that need to be answered. The last part of the conceptual design is to determine the exact definitions of the main concepts that are used in the research. This also leads to boundaries on what to include and what not to include in the research *(Verschuren & Doorewaard, 2007)*.

The objective of this study, as part of the larger research project is the following:

> *To design a conceptual model of the IEP, to determine the input data for the simulation model, and to verify and validate the final simulation model.*

The research model on how to reach this objective can be found in Figure 2: The research model of this study.

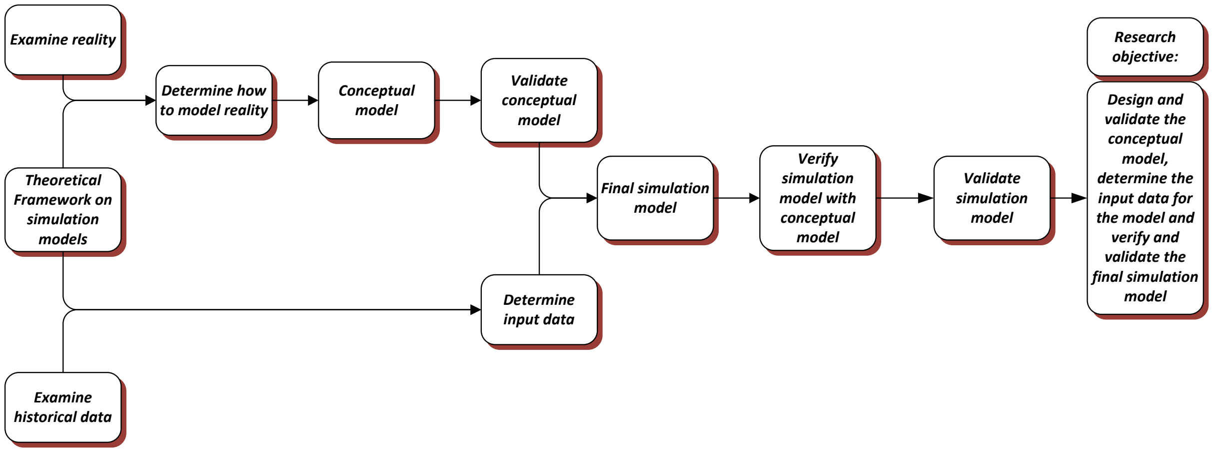

Figure 2: The research model of this study

From this research model, some central research questions can be determined. To answer the central research questions, several sub questions need to be answered.

- *What is known about simulation models in general and about using simulation in healthcare? (Chapter 3)*
    - What are the steps in designing a simulation model?
    - What are the pitfalls of designing a simulation model?
    - Are there examples of other simulation studies related to healthcare logistics?

- *How are the processes structured at the Integrated Emergency Post? (Chapter 4)*
    - How do patients enter the system?
    - Which process steps can be identified from door to door at the IEP?
    - What are the different routes through the system?
    - What kind of, and how many, employees work at the IEP at different time intervals?
    - What resources are used at the IEP?

- *How can the processes at the Integrated Emergency Post be modeled? (Chapter 4 and Chapter 5)*
    - Which assumptions are made?
    - Are the made assumptions realistic?
    - What input data is needed for the simulation model?

- *How usable is the final simulation model? (Chapter 6)*
    - How is the simulation model structured?
    - Does the programmed simulation model correspond with the conceptual model?
    - Are the model outcomes realistic?
    - Do the stakeholders, such as the future users of the model, agree with the model?

Finally, to conclude this conceptual design, we have to determine the boundaries of this study. The subject of this research is the integrated emergency post as being the collaboration between general practitioners and the emergency department of the hospital. The general practitioners post is only opened when the general practitioners do not have their own practices open, being outside regular office hours. Therefore we decided that this research only covers the situation outside of regular office hours. This means: Monday through Friday from 5:00 p.m. until 8:00 a.m., and Saturdays and Sundays for the full days.

The starting point of the processes of the IEP is the moment a patient has first contact with employees of the IEP. This can be through calling the IEP for advice or for an appointment, or when a patient physically enters the IEP. The end of the process is defined as the moment that the patient leaves the IEP, either to go home or to be admitted to the hospital for further treatment. Only treatment that takes place at the GP post or at the emergency department of the hospital is included. We do not include follow ups such as admission or follow up appointments at the policlinic. When a patient enters the system via an ambulance, only the processes from the moment the patient physically enters the emergency department are included in the research.

2.5.2 The technical design

After determining what is going to be researched, the technical design of a study determines how to research it. The technical design focuses on how, where and when research is performed to answer the designed research questions. The first step is to determine the research strategy, secondly a plan is drawn up to generate the necessary research material and finally a schedule is made for performing the research *(Verschuren & Doorewaard, 2007)*.

The research strategy concerns the way in which the research is going to be performed. In order to reach the objective of this study, a literature study needs to take place. However, since the IEP is a new concept, the functioning of the IEP can not be found in any literature and has to be experienced by observing the IEP in practice. Also many conversations with employees from the IEP are necessary to get more insight into the patient flows. Designing the conceptual model for the simulation is an iterative progress of making assumptions and checking these assumptions with those involved.

This research strategy is strongly connected to the way in which research material is going to be generated. As mentioned above, a great deal of the qualitative material has to be gathered from the actors involved by asking questions. With respect to the quantitative data, the GP post and the ED each have their own data management system from which historical data can be extracted, for example on the number of patients taking certain routes through the IEP or needing certain diagnostic examinations. This data can help to either reject or support the assumptions we made based on the experience employees have with the system, for example on when the IEP is the busiest. We also use this data as input for the simulation model. With this data and from the designed conceptual model, the final simulation model is developed by dr. ir. Martijn Mes from the University of Twente. When the simulation model is finished a data analysis of the output data is done to verify whether the translation from conceptual model to simulation model is done correctly.

In Chapter 3 we look into the available information on simulation models in general and in healthcare. Starting from Chapter 4, the design of the conceptual model begins by describing reality and making assumptions based on the experiences of involved actors. In Chapter 5, a data analysis of historical data helps us to test whether the assumptions were correct. Also parts of the analyzed data will serve as input data for the simulation model. Based on the information described in Chapter 4 and 5, the simulation model is developed. In Chapter 6 we go into the verification and validation of this model. In Chapter 7 we summarize the strong and weaker points of the model and the conclusions of this study. Finally, in Chapter 8 we give a description of the future work related to this study.

Chapter 3 Theoretical Framework

The first step of this research is to do a literature study to find out what is already known about the subject. For this study, this means that we focus on three subjects: simulation studies in general, simulation studies in healthcare and the collaboration between GP posts and EDs.

3.1 Simulation

"*Simulation* is the process of designing a model of a system and conducting experiments with this model for the purpose either of understanding the behavior of the system or of evaluating various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system"*(Shannon, 1975)*.

In this study the simulation model is going to be used to test interventions and thus evaluating various strategies. To be able to draw useful conclusions from the results, we must be sure that the simulation model is a good representation of reality that leads to trustworthy results. Law (2007) provides some guideline for designing simulation studies. These steps are given in Figure 3.

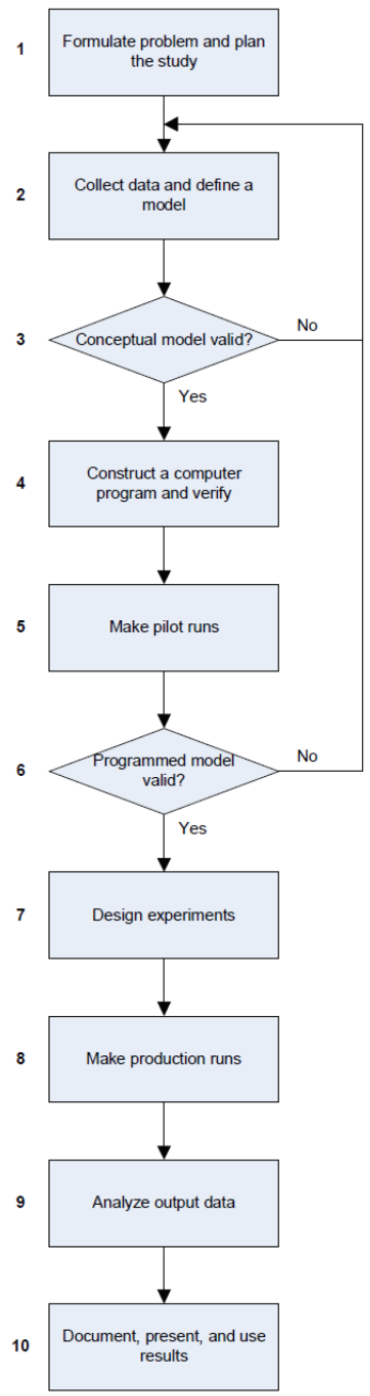

Figure 3: Steps in a simulation study (Law, 2007)

In the first six steps, as given by Law (2007) much emphasis is on verifying and validating the conceptual and programmed model. It is important to understand the difference between verification and validation. Law states:

- "*Verification* is concerned with determining whether the 'assumptions document' has been correctly translated into a computer program, which means debugging the simulation computer program".
- "Validation is the process of determining whether a simulation model is an accurate representation of the system, for the particular objectives of the study.

The intended result of verification and validation is to establish credibility for the model and its results. "A simulation model and its results have credibility if the manager and other key project personnel accept them as correct"*(Law, 2007)*.

In this research we follow the steps of Law. The first step, "formulate problem and plan the study", is described in Chapter 2. The next step, "collect data and define a model", is described in the Chapters 4 and 5. In Chapter 6 we give a short account of the programmed simulation model and we describe the verification and validation techniques that were used. The other steps, as described by Law, will be performed in future research.

Law also lists some pitfalls to the successful completion of a simulation study, that we have to take into account *(Law, 2007)*:

- Failure to have a well-defined set of objectives at the beginning of the simulation study.
- Failure to have the entire project team involved at the beginning of the study.
- Inappropriate level of model detail.
- Failure to communicate with management throughout the course of the simulation study.
- Misunderstanding of simulation by management.
- Treating a simulation study as if it were primarily and exercise in computer programming.
- Failure to have people with knowledge of simulation methodology and statistics on the modeling team.
- Failure to collect good system data
- In appropriate simulation software.
- Obliviously using simulation software products whose complex macro statements may not be well documented and may not implement the desired modeling logic.
- Belief that easy-to-use simulation packages, which require little or no programming, require a significantly lower level of technical competence.
- Misuse of animation.
- Failure to account correctly for sources of randomness in the actual system.
- Using arbitrary distributions as input to the simulation.
- Analyzing the output data from one simulation run (replication) using formulas that assume independence.
- Making a single replication of a particular system design and treating the output statistics as the 'true answers'.
- Failure to have a warmup period, if the steady-state behavior of a system is of interest.
- Comparing alternative system designs on the basis of one replication for each design.
- Using the wrong performance measures.

The book of Law (2007) gives us insight into the issues of simulation and the steps that in general have to be taken in every simulation study. In the next section we look into the simulation studies that already have taken place in the field of (acute) health care.

3.2 Simulation studies in healthcare

The fact that discrete event simulation can be used to perform experiments, without having to disturb the real world system, makes it a very suitable tool to use in the field of healthcare logistics. Jacobson, Hall & Swisher (2006) state: *"Discrete-event simulation is an operations research modeling and analysis methodology that permits end-users (such as hospital administrators or clinic managers) to evaluate the efficiency of existing health care delivery systems, to ask "what if?"questions, and to design new health care delivery system operations. […] Such information allows health care administrators and analysts to identify management alternatives that can be used to reconfigure existing health care systems, to improve system performance or design, and/or to plan new systems, without altering the existing system."*

Through the years, several simulation studies have been done in various fields of health logistics. An overview of the use of discrete event simulation in healthcare from the mid 70s till the year 2006, can be found in Chapter 8 of the book "Patient flow: Reducing delay in healthcare delivery" *(Jacobson, Hall, & Swisher, 2006)*. Among others, several articles are listed that focus on methodologies for success full simulation in healthcare. Some of them offer structured tutorials, such as the studies of Banks and Carson (1987) , and Mahachek (1992). The work of Eldabi and Paul gives an iterative approach for designing a simulation study in healthcare *(Eldabi &*

Paul, 2001). Other referenced articles describe performed simulation studies, which are separated in two groups based on the purpose of the study: 1) optimization and analysis of patient flows and 2) allocation of assets to improve the delivery of services. The simulation model that will result from this study, can be used to test iterations with respect to both subjects. Therefore we will focus on simulation studies from both groups, which took place in the area of acute care.

In 2004, Miller et al. published an article on which steps to take to “go from an As-Is ED configuration to the best To-Be configuration”, in which they used the steps as defined by Law (2007) and applied them to the ED *(Miller, Ferrin, & M.G.Messer, 2004)*. Around the same time Sinreich and Marmor (2004) did research to develop a flexible tool that can be used in different ED settings. The emphasis for the simulation tool is on making it “flexible, intuitive and simple to use”, and having it “contain default values for most of the system’s parameters”*(Sinreich & Marmor, 2004)*.

Since one of the key performance indicators for an emergency department is the waiting time for patients, many studies, as listed by Jacobson, Hall and Swisher (2006), focus on decreasing these waiting times. In 1993, Ritondo and Freedman used discrete event simulation to decrease the waiting time in the emergency room and increase patient throughput, by changing procedural policies *(Ritondo & Freedman, 1993)*. Takakuwa and Shiozaki, did research on minimizing patient waiting times by using a different procedure for planning operations that take place at the emergency department *(Takakuwa & Shiozaki, 2004)*. Also some studies were done on the use of fast-tracks to decrease waiting times and improve patient flow. Two examples are the research of Kirtland et al (1995), in which eleven alternatives were tested using discrete event simulation, and the study of Blake et al (1996) in which a fast-track was tested for patients with minor injuries.

On the topic of resource allocation too, several simulation studies have been performed at emergency departments. Most of these studies focus on optimizing the number of staff members and the way in which they are scheduled. For example, Badri and Hollingsworth did research on how different operational scenarios have impact on scheduling a limited number of staff members. They also looked at the consequences of different demand patterns. One of the tested scenarios was not serving patients that do not belong at the emergency department. In 2003, Baesler et al, predicted the amount of time patients spent at the emergency department by using discrete-event simulations. The results were used to design experiments to minimize the number of required staff members *(Beasler, Jahnsen, & DaCosta, 2003)*. Another example is a study by Klafehn and Owens (1987), in which research was done on “determining the relationship between patient flow and the number of staff available in an emergency department”. In this study, the effect of changes in the division of tasks between staff members on the waiting times and patient throughput, was analyzed *(Klafehn & D.Owens, 1987)*. In different studies, research was done with respect to other resources, such as medical equipment. Lopez-Valcarcel and Perez (1994) “recommended that investments in human resources would be more effective than investments in newer (better) equipment”*(Jacobson, Hall, & Swisher, 2006)*. This recommendation contradicts that of Godolphin et al. (1992), who conclude from their research on resource allocation at an emergency department, that the number of staff member can be reduced if better equipment were purchased and automation was applied.

Finally we want to refer to an example of a simulation study that took place in the Netherlands. In 2006, J.C. van Schuppen performed a research study in which discrete-event simulation modeling was used to test different interventions at the Emergency Department of the Academic Medical Centre in Amsterdam. The goal of this study was “to provide AMC with a versatile and comprehensive simulation tool that improves the ED manager's ability to anticipate on the impact of changes, as well as to evaluate the effectiveness of current practices” *(Schuppen, 2006)*. She performed this research following T. Hoomans (2002) who also performed a simulation study at the ED of the AMC, but whose research, according to J.C. van Schuppen “was not userfriendly and quite limited". In 2007, the simulation model from van Schuppen was used to test several scenarios for the ED of the AMC hospital *(Peijz, 2007)*.

At this point, we have an overview of various studies that were performed at emergency departments and which made use of discrete-event simulation. The next step is to look at what research is already done on the subject of cooperation between GP posts and EDs.

3.3 Collaboration between GP posts and EDs

At this moment, not much quantitative research is done on the effects of collaboration between GP posts and Emergency Department. However, some qualitative studies and case studies have been performed. For example, in 2009, Coenen published a report with an overview of organizational developments of GP posts and EDs towards more collaboration. He concludes that these two organizations have different perspectives on patient care, and that collaboration has the best chance at success if both organizations keep their own perspective and thus collaborate, but don't integrate *(Coenen, 2009)*. In 2008, a case study is performed by Kool et al. that "compares the efficiency and patient and employee satisfaction in IEPs with those in two GP posts and two A&E departments" *(Kool, Homberg, & Kamphuis, 2008)*. They conclude that "IEPs could be a promising innovation to organize emergency care more efficiently; however, it might take time to convince professionals of the possible advantages."

Several studies conclude that the development of models for collaboration in the delivery of acute care is a good development because it will yield more effective, efficient and more patient centered care *(Klink & Bussemaker, 2008; Ham, 1998)*. However there is little to no quantitative prove that the implementation of a collaboration between a GP post and an ED, such as the IEP, will actually lead to such results. Therefore part of the objectives of this overall research project is to form a scientific foundation on how to reach an optimal process design for the integrated emergency post and to give an overview of quantitative results of opening and IEP.

As preparation for this research project, Smid did a study at the IEP in Almelo *(Smid, 2010)*. In his thesis he gave a description of the situation before and after the implementation of the Integrated Emergency Post. He also compared the situations with respect to some performance indicators, such as amount of waiting time on the phone and the throughput times. At the moment this study was performed, the IEP has only been opened for three months and only limited data was available. Therefore part of the overall research project is to perform a more extensive data analysis, to compare the situations before and after the implementation of the IEP and analyze the effects of the IEP.

Chapter 4 Conceptual Model

In this chapter, we start with designing the conceptual model of the IEP. The first step is to describe the processes as they take place in reality (4.1). Since not all patients go through exactly the same processes, there must be some variables that influence how a patient goes through the IEP. We have to identify these variables and determine how these are interrelated (4.2). For each process step a patient has to undergo, we have to identify exactly what resources, such as personnel, a room or equipment, are needed (4.3). Also, every process step takes a certain amount of time, which can depend on patient specific characteristics. Therefore we have to make assumptions on which variables influence processing times (4.4). Finally, we have to identify which events at the IEP serve as a trigger for other actions (4.5).

4.1 Identifying the process steps

The first step in designing the simulation model is to look at the different processes in the IEP in detail. How do patients arrive, what processes within the IEP are involved, and how do the patients leave the IEP?

There are three ways in which patients can enter the system of the IEP: 1) by calling the IEP, 2) by coming to the IEP as a self-referral or 3) by coming to the emergency department through an external referral. In this last group, the patients are referred to the ED for example by the call centre of the national alarm number 112 or by other hospitals.

When a patient calls the IEP, a GP assistant answers the phone and performs a telephonic triage to determine the urgency of the patient. Depending on the urgency and the symptoms of the patient, several things can happen:

- The GP Assistant gives medical advice to the patient and this is sufficient. The patient leaves the system after the telephone call is disconnected.
- The patient gets an appointment time for a consultation at the GP post.
- A GP is sent to the home of the patient for a visit. Upon arrival, the GP can often treat the patient at home, after which the patient leaves the system. In some cases the GP decides to call an ambulance to take the patient to the hospital for further examination or treatment. The patient is then brought directly to the ED.
- The GP Assistant gives medical advice and decides that the symptoms of the patient are urgent enough to send an ambulance immediately to take the patient to the ED.

Patients that do not call to the IEP before coming to the hospital, the so-called self-referrals, have symptoms and an urgency that are unknown upon arrival at the IEP. Therefore the first step for these patients is to perform a triage. This triage is done by one of the GP assistants and can have the following outcomes:

- The patient gets medical advice from the GP assistant and does not require any follow up. The patient can go home and leaves the system.
- The patient gets an appointment time for a consultation and meanwhile stays in the waiting room.
- When the urgency is high, the GP assistant can choose to directly refer the patient to the ED for further examination or treatment.

When a patient gets a consultation at the GP post, the following decisions can be made:

- The patient gets medical advice and goes home.
- The patient is referred to the ED for further examination or treatment

- In case there is the suspicion of a bone fraction, the GP can refer the patient to the radiology department for an X-ray. When the bone appears to be broken, the patient is referred to the ED for treatment. When the bone doesn't appear to be broken, the patient is send back to the GP for further advice before going home.

As described above, there are several ways for a patient to arrive at the ED, both through the GP post as external. Upon arrival at the ED, a second triage is performed. This is done because the ED uses a different triage system than the GP post. Where the urgencies at the GP post rank from U4 (not urgent) to U1 (very urgent), at the ED a patient's urgency is categorized as being blue (not urgent), green, yellow, orange, or red (very urgent).

After triage, the patient history is registered, first by an ED nurse or physician assistant and then again by a medical resident. Next, the need for diagnostic tests is determined. In our model we include the following diagnostic tests: X-ray, CT scan, Echo, ECG, and Laboratory Analysis. Later in this chapter (Section 4.2.3) we will discuss these diagnostics in further detail.

When a patient has undergone all necessary tests, the medical staff determines the diagnosis and starts treatment. After the treatment there are several ways for a patient to leave the system. The ED registration has a total of nine destination categories, which we can reduce to 3 general categories. Patients can either (i) leave the system, (ii) be admitted into the hospital or (iii) be transferred for admission in another hospital. Together the processes described above form the IEP. A flowchart of these processes is given in Figure 4. In this flowchart, the arrival route of the self-referrals is indicated with blue lines. The IEP process is split into three parts. Part A starts at the arrival of patients into the system (physically or by phone), part B starts with a consultation at the GP post, and part C starts upon arriving at the ED. *For the model, we assume the three parts A, B, and C of the IEP process to be independent.* This means that once a patient has a consultation, the outcome of that consultation has no relation to how the patient got to that consultation. Similar for the ED, once a patient enters the ED, the processes that take place there do not depend on how the patient got to the ED.

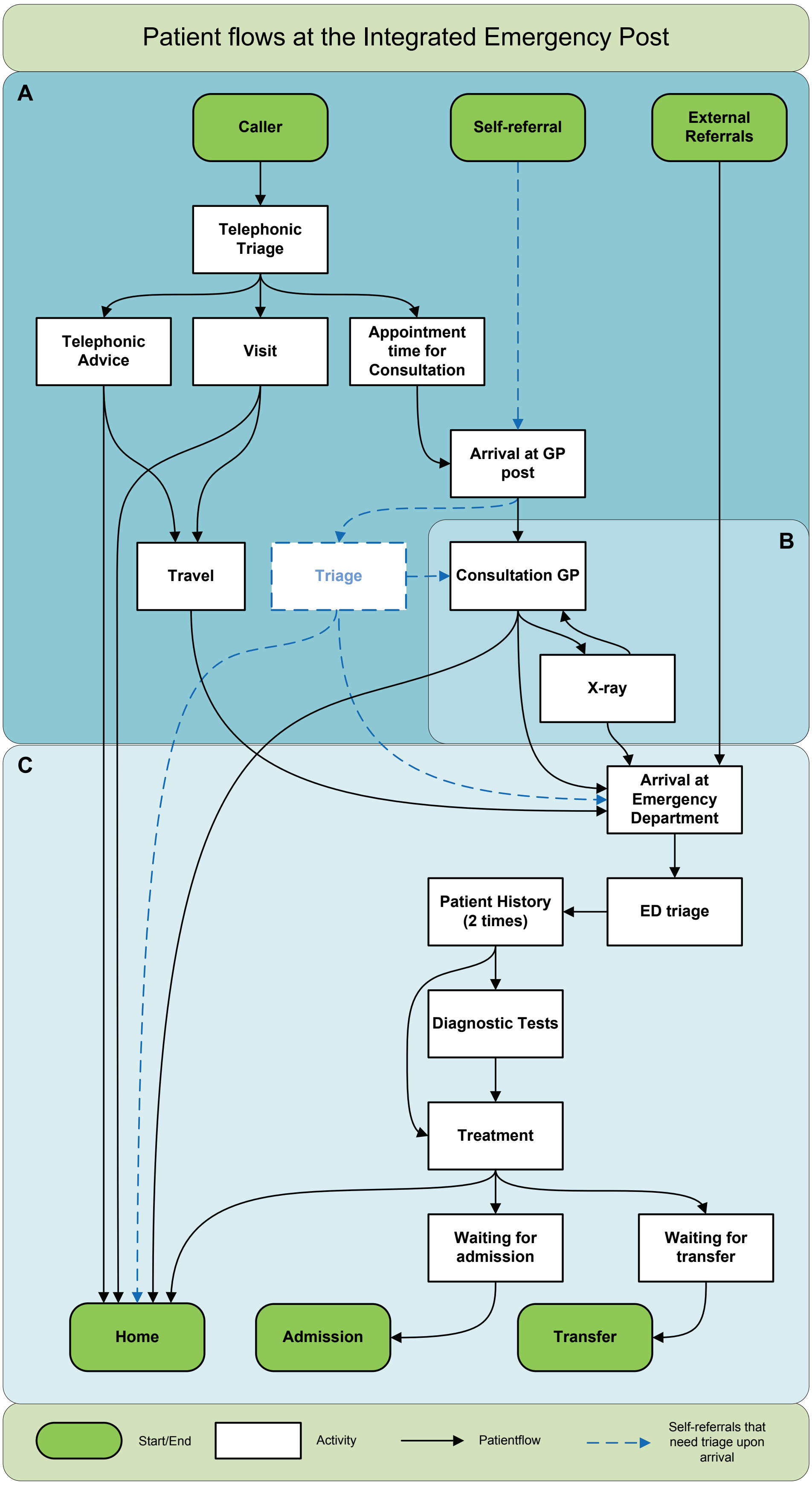

Figure 4: Flowchart of the processes of the IEP

In the simulation model, the fact that we assume the three parts A, B, and C independent can lead to unrealistic results when looking at the route through the IEP for an individual patient. For example, there is a possibility that a patient follows the path from consultation at the GP post, through X-ray, to the ED and then gets another X-ray as part of the diagnostic process, while in reality this would rarely happen. However, to get an idea of the general processes and their performance, several years will be simulated and as a result individual peculiarities will average out. As stated by Lowery (1996): “While formal statistical tests may lead to the conclusion that a model is not an accurate representation of the real world system under investigation, the model may still be valid for the purpose for which it is intended. This is especially true for models that are designed primarily for comparing alternatives than for predicting absolute answers.” To increase the resemblance of the simulation model to reality, we assume that the route that an individual patient takes is dependent of one or more variables. In Section 4.2 we look further into what variables have to be taken into account and we make assumptions about the dependencies within the parts A, B, and C.

From the flowchart of processes at the IEP, we can derive for each of the parts different paths through the system that can be taken by patients. For part A we identified the following paths (Table 2):

Table 2: Eight possible paths for entering the IEP

A1	Self-referral - Triage - ED
A2	Self-referral - Triage - Home
A3	Self-referral - Triage - Consultation GP post
A4	Caller - Telephonic Triage - Telephonic Advice - Home
A5	Caller - Telephonic Triage - Telephonic Advice - ED
A6	Caller - Telephonic Triage - Visit - Home
A7	Caller - Telephonic Triage - Visit - ED
A8	Caller - Telephonic Triage - Consultation GP post

From these ‘A-paths’, two of the routes take the patient to part B: a consultation at the GP post, namely the paths A3 and A8. From here we can again identify several options (Table 3):

Table 3: Four possible paths starting with a consultation at the GP post

B1	Consultation GP post - Home
B2	Consultation GP post - X-ray - Follow-up Consultation GP - Home
B3	Consultation GP post - X-ray - ED
B4	Consultation GP post - ED

When arriving at the ED, through the paths A1, A5, A7, B3, or B4, the basic path for every patient is the same. The only variances that will occur are with respect to the number and types of diagnostics. Also for leaving the ED, there are several options: going home, being admitted, or being transferred. The standard path at the ED is:

Arrival at ED – ED triage – Patient History – (0 – 5 types) diagnostic tests – treatment – leaving ED

At this point, we know what possible routes can be taken by the patients, but how to determine which patient takes what route? In reality, these routing decisions depend on several variables, such as time, urgency, type of patient, etcetera. In the next section, we are going to determine which variables have to be taken into account and how the routing decisions can be modeled.

4.2 Process dependencies

Although we stated in the previous paragraph that parts A, B, and C are assumed to be independent, within these parts there are dependencies that influence the route a patient will take. In this section we make assumptions on the relationships between different variables like time and urgency. These assumptions are based on the experience of staff members of the IEP and will be tested with a data-analyses in Chapter 5.

4.2.1 Patient Arrivals

For the arrival of patients, both at the GP post (both physically and by phone) as externally referred to the ED, we know that the rate in which the patients arrive is time dependent. The number of patients arriving varies between hours, between days, and from week to week. According to the staff members we can identify busy hours and quiet hours, which are the same for every weekday. Since the IEP is opened in the weekends for 24 hours a day, the distribution of busy and quiet hours is different on Saturdays and Sunday. Although every weekday has the same busy hours, there all still differences between the weekdays. Namely, some days are relatively busier than others. For example staff members identify Mondays and Fridays as relatively busy days, and Tuesday and Thursday as relatively quiet days. On top of this, there are seasonal influences that cause the number of arriving patients to vary from week to week. For example the winter period always causes the number of patients to rise.

To take into account all the factors mentioned above, we decided to model the arrivals according to the following assumptions:

- *Patient arrivals follow a Poisson process with λ being the average number of patients arriving in the time interval.*
- *A time interval has the length of one hour, so for every hour we need to come up with a λ_h.*
- *The average number of patients per hour varies per hour, but also per day and per week. Therefore, we can express the average number of patients arriving in a time interval as $\lambda_{h,d,w}$.*
- *There is no relation between the day of the week and the week of the year. This means that throughout the entire year, every week has the same busy days and the same quiet days.*
- *The relation between hour of the day and day of the week is as follows: For the weekdays, Monday till Friday, the pattern in busy and quiet hours is the same for all days, but on Saturday and Sunday this pattern differs. Not only do the patterns differ in weekends compared to weekdays, because of the fact that on those days the IEP is open between 8:00 and 17:00, there are also differences between the pattern of Saturdays and that of Sundays.*
- *In the simulation model, abnormal patterns of arrivals because of public holidays are not included*

We now have to generate the parameter $\lambda_{h,d,w}$, taking all influencing time factors into account. To do this we introduce the following notation:

$\lambda_{h,d,w}$.	The average number of patients arriving in the hour h, on day d, in week w.
$\alpha^I_{h,d}$	The arrival rate of patients through the IEP, in hour h on day d, with d = 1,…,5 on weekdays, d = 6 on Saturday and d = 7 on Sunday.
$\alpha^E_{h,d}$	The arrival rate of external patients at the ED, in hour h on day d, with d = 1,…,5 on weekdays, d = 6 on Saturday and d = 7 on Sunday.
β^I_d	The day factor for day d for d = 1,…5, which represents the fluctuation in the number of arrivals between the weekdays, for the patients arriving through the IEP

β_d^E The day factor for day d for d = 1,…5, which represents the fluctuation in the number of external arrivals at the ED between the weekdays.

γ_w^I The week factor for week w = 1,…,52, which represents seasonal fluctuations for arrivals through the IEP.

γ_w^E The week factor for week w = 1,…,52, which represents seasonal fluctuations for external arrivals.

The arrival rates $\lambda_{h,d,w}$. are given by:

$$\lambda_{h,d,w} = \begin{cases} \alpha_{h,d}^I * \beta_d^I * \gamma_w^I & \textit{For patients arriving through the IEP} \\ \alpha_{h,d}^E * \beta_d^E * \gamma_w^E & \textit{For external arrivals} \end{cases} .$$

The rate for d = 1,…,5 is according to the assumptions above the same, meaning

$$\alpha_{h,1}^I = \alpha_{h,2}^I = \alpha_{h,3}^I = \alpha_{h,4}^I = \alpha_{h,5}^I,$$

and
$$\alpha_{h,1}^E = \alpha_{h,2}^E = \alpha_{h,3}^E = \alpha_{h,4}^E = \alpha_{h,5}^E.$$

Using the approach described above, we can determine the number of patients per hour for the arrivals through the IEP as well as for the external arrivals at the ED. In Section 5.1, we perform a data analysis to determine the values of the α, β and γ for each time interval.

4.2.2 Other GP post Dependencies

Not only the number of patients is time-dependent, also *the urgency of the patient's symptoms depends on what time the patient comes in.* Overall, the staff members of the IEP see the following patterns: Patients that arrive in the middle of the night tend to have a higher urgency, because patients with less urgent complaints often wait for morning to come, to go to their own GP. Patients that arrive early in the evening often have less urgent problems. The presumption of the staff members is that often these people do have some complaints, but did work during the day and therefore could not go to their own GP. On Saturday and Sunday, the patients that arrive between 3.00 a.m. and 8.00 a.m. also seem to have a higher urgency. In Section 5.2 we perform a data-analysis to check these assumptions.

As described in Section 4.1, all patients entering the system are categorized in one of the paths A1-A8. We make the assumption that *the way in which the patient enters the IEP (path A) depends on the urgency of the patient.* For example: a patient with very urgent symptoms will unlikely follow path A2: Self-referral – Triage – Home. This assumption will be tested with historical data in Section 5.3.1.

As stated in Section 4.1, the decisions made in part A are of no influence on the outcome of a consultation in part B. Therefore, we assume that *the probability of any path B is independent of other variables.* We base the probabilities of getting a certain outcome on historic data which we examine in Section 5.3.2.

4.2.3. ED Dependencies

When a patient arrives at the ED, decisions must be made with respect to all processes that take place in part C of Figure 4. The first step is to (re)determine the urgency of a patient according to the scale from blue to red. We already decided to base the urgency on the arrival time. However at the ED, some patients arrive through the GP post and some are external arrivals. *For the external arrivals, we can base the urgency on time the same way we did for the GP post urgency*. But for the patients that already had contact with the IEP (by phone or physically) an urgency was already determined according to the scale used at the GP post (U1 – U4). We assume *the GP post urgency is related to the ED urgency*. After all it seems unlikely that a patient that enters the system with very urgent symptoms (U1) is scaled at the ED with low urgency (the 'blue' category). This assumption will be tested by data analysis in Section 5.4.

The next step is to determine whether a patient needs certain diagnostic tests. From experience of the staff members we conclude that the need for diagnostic tests is strongly dependent on the type of patient, for example: in need of what specialty is the patient and what kind of symptoms does the patient have? To include these factors in the simulation model we decided to categorize all patients in 10 simulation groups. These groups are defined by the 8 most common 'Diagnosis Related Groups' (DRG's) from one year after introducing the IEP and two rest groups: surgical specialties and contemplative specialties. The resulting 10 simulation groups can be found in Table 4.

Table 4: Simulation Groups according to symptoms

Groupnr.	*Description Simulation Group*
1	Surgical - Trauma - Fracture
2	Surgical - Trauma - Wound
3	Surgical - Trauma - other
4	Surgical - Abdomen
5	Surgical - Rest
6	Neurological - Stroke
7	Pulmonary medicine
8	Internal medicine
9	Cutting specialties - other
10	Contemplative specialties - other

The probability that a patient is being assigned to a certain simulation group is assumed to be time dependent. For example, on Saturday afternoon many patients arrive with possible fractures as a result of playing sports. Once a patient is categorized in one of the simulation groups, the probability that he needs diagnostic tests is determined. We assume that *the probability of needing a type of diagnostic test is depending on the simulation group of the patient***.** In the model we will take into account 5 types of diagnostic tests: Labs, X-rays, Ultrasounds, ECG's and CT scans. We assume *the need for the different types of diagnostic tests is independent of the need for other types of tests.* That means we will look at probability that a patients from a certain simulation group needs, for example, an X-ray. But we will not look at the probabilities of a patient needing an X-ray together with a CT scan**.** Another fact that needs to be taken into account is that some patients may require more than one test per diagnostic type. Think for example about a patient that needs an X-ray of both his upper arm and shoulder. *We assume that the number of tests per diagnostic type is depending on the simulation group of the patient.*

After being treated, the patient can leave the IEP system either by (i) going home, (ii) being admitted or (iii) being transferred. *The probability of each of the exit-options depends on the simulation group in which the patient is categorized.* Patients with a fracture (Group 1) almost never get admitted, while patients with neurological problems have a big probability of being admitted. For the simulation model, the destination of the patient is relevant since patients that need to be admitted might have to wait for a bed at a ward to become available. Also, patients that need a transfer have to wait for an ambulance. These patients stay in their ED room while waiting to move along and exit the IEP.

Now we have determined many dependencies that influence whether a patient needs to go through certain process steps. The next step is to define which resources are needed to enable a patient to go through those steps.

4.3 Resources

For the processes at the IEP, three types of resources may be needed: personnel, rooms, and equipment. In the next part, we look at the different types of personnel, rooms and equipment at the IEP and the modeling of these different types. Also an overview is given of the necessary resources per process step.

4.3.1 Personnel

We can identify different types of personnel, based on their responsibilities and qualifications. However, only the employees with direct influence on the processes and with clear tasks within the processes will be included in the simulation model. The following types of personnel will be included in the model:

- GP Assistant: Answers phone calls, gives telephonic advice.
- Triage Assistant: Is a GP assistant with the special task to triage all self-referrals. When there are no self referrals waiting for triage, the triage assistant also answers phone calls.
- GP: gives consultations and goes on patient visits.
- ED Nurse: Does triages, takes histories, performs lab and ECG tests and applies casts on fractures.
- Resident: Takes patient history, reviews test results and performs treatments.
- Medical Specialist: Is called when a resident does not succeed in diagnosing or treating a patient.
- Physician Assistant: May perform certain protocolled procedures at the GP Post as well as at the ED.
- Diagnostic Nurse: Performs diagnostic tests.

One of the staff members that will not be modeled is the receptionist. Although the receptionist plays an important role in the communication between staff members, the tasks involved have only indirect influence on the process steps as described in Section 4.1. Also, the coordinating GP will not be modeled. On evenings and weekends there is always one extra GP on shift to take care of coordination and communication, for example with respect to the location of the visiting GPs. However, the GP who is assigned to this role in principle doesn't spend time consulting or visiting patients. Therefore there is only indirect influence on the main processes. This does mean that after simulating interventions we have to keep in mind that in reality one extra GP must be taken into account on top of the number of GPs in the simulation, to take this coordinating role.

At the ED, the residents are split in to two groups: medical residents and surgical residents. This division determines which patients a resident will diagnose and treat depending on the simulation group. *Medical residents will help patients from the simulation groups 6, 7, 8, and 10, surgical residents from simulation groups 1 till 5 and 9.*

As stated in the list above, at the ED, the medical specialist only performs certain tasks if his help is required by the resident. This means that in principle the resident will perform the ED treatment, but with a certain probability the specialist needs to come to the ED to help. *We assume that the probability of a medical specialist being required depends on the ED urgency of the patient.* Since medical specialists are not usually present at the ED, we have to take into account some extra time for the specialist, for waiting on his availability and for travel time to get to the ED. *We assume the time until arrival of the specialist to depend on the ED urgency of the patient.* This is because the urgency of the patient influences the hurry in which a specialist comes to the ED and for example whether he finishes his work elsewhere before going to the ED. We go further into determining the probabilities of requiring a specialist in Section 5.8.

Similar to the medical specialist, the diagnostic nurse is also an external resource that is called to the ED when needed. Therefore we have to take into account waiting times for the diagnostic nurse before starting certain diagnostic tests. *For each test type, a different kind of diagnostic nurse is required. We assume the diagnostic nurses only differ in the length of the waiting time before performing a diagnostic test.* These waiting times will also be determined in Section 5.8.

The table below shows an overview of different actors in the model and the processes from Figure 4. For every type of actor it is given which of the tasks it is allowed to perform (Table 5). In some cases this authorization depends on the urgency of the patient. This reflects the reality in which the authorization can depend on the severity and kind of symptoms. We see the five different types of diagnostic tests and who performs them. For the tests that are performed by a diagnostic nurse, the results have to be reviewed separately by someone from the ED staff. From the table we see that some tasks may be performed by more than one type of actor. How to decide which of the authorized actors performs the task will be discussed in Section 4.6.

Table 5: Overview of the model actors and the authorization to perform certain tasks at the IEP

Location	Task	GP Assistant	Triage Assistant	GP	ED Nurse	Resident	Medical Specialist	Physician Assistant	Diagnostic Nurse
GP post	Telephonic triage	U1 - U4	U1 - U4	-	-	-	-	-	-
GP post	Triage	-	U1 - U4	-	-	-	-	U1 - U4	-
GP post	Consultation GP	U3 & U4	U3 & U4	U1 - U4	-	-	-	U3 & U4	-
GP post	Visit	-	-	U1 - U4	-	-	-	-	-
ED	ED triage	-	-	-	Blue - Red	-	-	-	-
ED	Patient History (first time)	-	-	-	Blue - Red	-	-	Blue - Red	-
ED	Patient History (second time)	-	-	-	-	Blue - Red	Blue - Red	-	-
ED Diagnostic tests	Perform X-Ray	-	-	-	-	-	-	-	Blue - Red
ED Diagnostic tests	Perform Ultrasound	-	-	-	-	-	-	-	Blue - Red
ED Diagnostic tests	Perform Laboratory Research	-	-	-	Blue - Red	-	-	-	-
ED Diagnostic tests	Perform CT Scan	-	-	-	-	-	-	-	Blue - Red
ED Diagnostic tests	Perform ECG	-	-	-	Blue - Red		-	-	-
ED Diagnostic tests	Review results X-ray	-	-	-	-	Blue - Red	Blue - Red	-	-
ED Diagnostic tests	Review results Ultrasound	-	-	-	-	Blue - Red	Blue - Red	-	-
ED Diagnostic tests	Review resullts CT Scan	-	-	-	-	Blue - Red	Blue - Red	-	-
ED	Treatment at ED	-	-	-	-	Blue - Red	Blue - Red	Blue	-
ED	Cast Application	-	-	-	Blue - Red	-	-	Blue - Red	-

4.3.3 Rooms

A staff member can only perform a certain task if the necessary room is available. Several rooms are taken into account in the model. First we list the rooms that are directly needed to perform process steps (Table 6).

Table 6: Rooms included in the model

Room	Amount Available / Capacity
Call Centre	The number of phone calls that can be answered at the same time is depending on the number of GP Assistants, with a maximum of 7.
Triage Rooms	2; one for the GP post and one for the ED
GP Rooms	6; We do not differentiate between consultation and treatment rooms
ED Rooms	8; We do not differentiate between different types of ED Rooms.
X-Ray	2
CT Room	1
Plaster Room	2

Other areas that are taken into account in the model are the waiting area in the main hall for both GP post as ED patients. When staff members do not have tasks to perform in the model, they will be placed in either the living room (GP post) or the coffee room (ED).

When patients are referred to the ED by the GP post, their standard movements are to wait in the waiting room, go to triage to determine ED urgency, wait in the waiting room until an ED room is available and then move to an ED room.

When a patient at the ED goes to the CT scanner or X-ray, the ED room of this patient stays assigned to the patient and when the diagnostic test is finished the patient returns to the assigned ED room. In the mean time, no other patients make use of the ED room. The other diagnostic tests (lab, ECG and ultrasound) take place at the ED room of the patient.

Treatment of the patient at the ED takes place at the ED room of the patient. One exception is the treatment for patients from simulation group 1: surgical – trauma – fracture. These patients are all assumed to need casting and therefore *the treatment of simulation group 1 takes place at the plaster room.*

4.3.4 Other resources

Besides a staff member and the appropriate room, in some cases additional resources are necessary too. In the model, this is the case for making an ECG or an ultrasound. Devices for these diagnostic tests are portable so the tests take place at the ED room of the patients.

4.3.5 An overview of necessary resources per process step

Table 7 gives an overview of the resources that are necessary per process step of the IEP. When multiple staff members are indicated, this means that each of them could perform the task. Each task needs a maximum of one staff member, except for the treatment. When there is determined that a specialist is necessary for the treatment, the specialist as well as the assigned resident will be present in the ED room of the patient during treatment. The call centre in which the telephonic triage takes place is a stage room. The patient is not physically inside this room when the triage is performed. Also more than one staff member (GP assistants and/or triage assistants) can be present in this room, since multiple phone calls can be handled in parallel. In Table 7 we see that for the reviewing of test results, no room is necessary. This is because the resident or medical specialist can perform these tasks without the patient being present.

Table 7: Necessary resources per process step

Task	Staff Member	Room	Additional Resources
Telephonic triage	GP Assistant / Triage Assistant	Call Centre	-
Triage	Triage Assistant / Physician Assistant	Triage Room 1	-
Consultation	GP Assistant / Triage Assistant / GP / Physician Assistant	GP Room	-
Visit	GP	Patients Home	-
ED triage	ED Nurse	Triage Room 2	-
Patient History (first time)	ED Nurse / Physician Assistant	ED Room	-
Patient History (second time)	Resident	ED Room	-
Perform X-Ray	Diagnostic Nurse	X-Ray	-
Perform Ultrasound	Diagnostic Nurse	ED Room	Ultrasound Device
Perform Laboratory Research	ED Nurse	ED Room	-
Perform CT Scan	Diagnostic Nurse	CT Room	
Perform ECG	ED Nurse	ED Room	ECG Device
Review results X-ray	Resident / Medical Specialist	no room needed	
Review results Ultrasound	Resident / Medical Specialist	no room needed	
Review resullts CT Scan	Resident / Medical Specialist	no room needed	
Treatment at ED	Resident / Medical Specialist / Physician Assistant	ED Room	
Cast Application	ED Nurse / Physician Assistant	Plaster Room	

Every action can only be performed if all necessary resources are available. In Section 4.6, we will look in more detail into the way in which this is going to be checked in the simulation model.

4.4 Processing times

After determining what processes take place at the IEP and how to decide which patients goes through which processes, we have to look at the length of these processes. The processing time for each process is determined by a stochastic distribution. This means that the same process can take a different amount of time for each patient. *At the GP post we assume the length of the processes (telephonic triage, triage, consultation and visit) to be distributed the same for every patient.* For the ED the situation is more complicated.

At the ED, for the processes of triage and taking patient history we assume that the processing times are deterministic, which means that they are exactly the same for each patient. But for the length of the diagnostics tests, there are some dependencies that have to be taken into account. For the model we assume that for each of the five tests there is one processing time to determine. However with some tests, like an X-ray, it is possible for a patient to need more than one photo taken. This, of course, has direct influence on the length of the diagnostic process. From interviews with involved employees we came to the following assumptions:

- *ECG: The processing time of an ECG is distributed the same for every patient that needs one. Every patient only gets one ECG.*
- *Lab: Every patient that needs laboratory tests goes through the process of taking samples only once. The processing time of this is distributed the same for everyone. After taking the samples a lab analysis is performed. Depending on the amount of factors to test on, this can either be a short analysis or a long analysis. Which lab analysis takes place is assumed to depend on the simulation group of the patient.*

- *X-ray: The processing time of making a photo is distributed the same every time. The number of photo's necessary for the patient depends on the simulation group the patient is in.*
- *CT scan: The processing time of making a scan is distributed the same every time. The number of scans necessary for the patient depends on the simulation group the patient is in.*
- *Echo: The processing time of making an echo is distributed the same every time. The number of echo's necessary for the patient depends on the simulation group the patient is in.*

After the diagnostic tests comes treatment. As stated before, for every treatment it needs to be determined whether a medical specialist is needed. This affects the processing time of the treatment since some actions can be performed quicker by a specialist than by a resident. This only applies for the processing time for the treatment itself, since we have to take into account that the specialist first has to be available and has to travel to the ED, which takes some extra time. Also the type of necessary treatment influences the processing time. This depends on the simulation group of the patient. *We therefore assume that the treatment time at the ED is influenced by the simulation group of the patient and by whether a specialist or a resident carries out the treatment.* When it is determined that a medical specialist is needed, the waiting time for this specialist depends on the urgency of the patient. During the waiting time for the specialist to show up, the resident is going to the next patient and keeps checking after each performed task whether the specialist has arrived yet. When a specialist performs the treatment, the resident has to be present in the room to witness and learn from the treatment. Therefore the treatment can only start when both the specialist as the resident is with the patient. In Section 5.9 we determine the distribution of processing time for the different process steps.

4.5 Model steps for creating patients

All information and assumptions that we described up till this point, have to be combined to be used as input for the simulation model. In the Sections 4.1 to 4.4 we have identified several variables that influence which processes a patient has to go through. A summary of these involved variables and their interdependencies can be found in Figure 5*: Dependencies between the involved variables for the IEP simulation model.*. As we can see, there are also indirect relationships that are taken into account. For example, in reality the way in which a patient enters the IEP (path A), is believed to be time dependent as well as depending on the GP post urgency. This dependency is modeled by making GP post urgency directly time dependent and path A indirectly via the urgency. Even though we assume the processes in the three parts A, B, and C (Figure 4) are independent, the processes are linked indirectly, because they are influenced by the same variables. This increases the probability of a realistic path for the individually simulated patients.

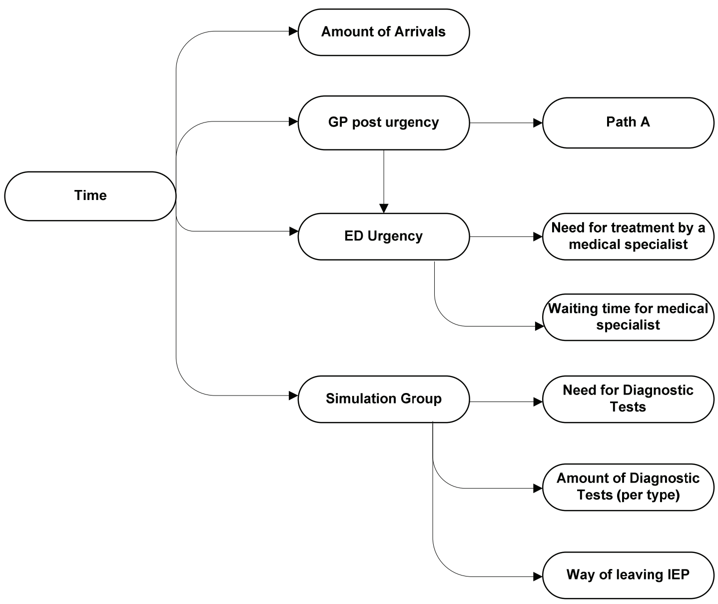

Figure 5: Dependencies between the involved variables for the IEP simulation model.

In the simulation model, the first step is to create the patients, using the approach we described in Section 4.2 Next, for every patient we have to assign values to all variables from Figure 5. To do this, we follow a sequence of steps:

1. Depending on the time of arrival: determine the GP post Urgency
2. Depending on the GP post Urgency: determine Path A
3. If path A ends at consultation: determine path B
4. If path A or B ends at the ED:
   - Depending on GP post Urgency: determine ED Urgency
   - Depending on time of arrival: determine Simulation Group
   - Depending on Simulation Group: determine necessary types of diagnostic tests
   - Depending on Simulation Group: determine for every requested type of diagnostic test the number of tests.
   - Depending on ED Urgency: determine the need for treatment by a medical specialist
   - If a medical specialist is required: depending on ED Urgency, determine the waiting time before treatment
   - Depending on the Simulation group and whether a specialist is required: Determine the ED treatment time of the patient
   - Depending on Simulation Group: determine the exit destination

Using these variables it is determined for each patient what processes needs to take place. The next step is to decide when these process steps can take place. In the next section we look into the way in which these decisions are made and how we can model this.

4.6 Decision making

In the previous sections we determined what processes need to take place and what resources are needed per process step. Now we have to look at how to determine when a task can take place. The first restriction that comes to mind is the fact that all resources that are needed for a task need to be available. Also, we have to make sure that the most important task is performed first. These two restrictions represent two situations in which decisions have to be made:

1. What happens when more than one staff member is available and authorized to perform a certain task? How is decided who is going to help the patient?
2. What happens when more than one patient is waiting for a process step? How do we decide which task is the most Important and is performed first?

As can be seen in Table 7, there are several process steps for which situation 1 can occur. In reality the decision on who performs a certain task is taken intuitively. For example, the decision can be influenced by factors such as expected future tasks and interaction between the staff members. These factors are very difficult to include in the simulation model, so we have to come up with a way to model this decision making process. One way to do this is to determine for each of the involved process steps the sequence in which staff members are preferred to do the task. For every task, we chose to sequence the staff members from least expensive workforce to most expensive. When multiple staff members are equal with respect to costs, we looked at who is supposed to perform the task in reality, according to the job description of the staff members. The medical specialist is not included in this sequence, since he is only called to the ED when needed for a certain treatment. The results of this sequencing can be found in Table 8.

Table 8: Order in preference of staff members for tasks for which more than one staff member is authorized

Task	*Order of preference of staff members*
Telephonic triage	1) GP Assistant 2) Triage Assistant
Triage	1) Triage Assistant 2) Physician Assistant
Consultation (U3 and U4)	1) GP Assistant 2) Triage Assistant 3) Physician Assistant 4) GP
Patient History (first time)	1) ED Nurse 2) Physician Assistant
Cast Application	1) ED Nurse 2) Physician assistant

In the simulation model, the sequence as given in Table 8 will be the sequence in which the staff members are checked for availability.

The second situation which calls for decision making is when more than one patient is waiting for a process step. How do we choose which waiting patient to help next? In practice this decision differs from one situation to another and is, among other things, based on the experience of the person making the decision. Since experience of staff members is hard to model, we let involved stakeholders choose which variable they assumed to be the most influential on the prioritizing of patients. From their answers we came up with the following prioritization rules:

- *First, we sort the waiting patients by urgency.*
- *Second, we sort the patients by how long they are already waiting for this specific task to be performed.*

Using these rules, all tasks of waiting patients can be ordered on a task list by rate of importance. Next, we are going to check for each task whether the required resources are available. The first task we come across where all resources are available, is the task that is going to be performed next. In Section 6.1, we will go further into the way in which these two decision making processes are modeled in the simulation model.

In this chapter, we have looked at what processes take place at the IEP, who performs them, and what other resources are necessary. Also, we determined how decisions with respect to patient and personnel prioritizing can be modeled. In order to model the IEP, we have made various assumptions, for example on process dependencies. Before translating these assumptions into the simulation model, we are going to test most of them in the next chapter. We do this by performing a data analysis on historical data from the GP post and the ED.

Chapter 5 Data Analysis

In the previous chapter, we have looked into how the IEP works. In this chapter, we are going to test some assumptions that were made in the previous chapter, by analyzing historical data of the GP post and the ED. Also, we are going to use the historic data to determine the parameter values that have to be put into the simulation model.

5.1 Arrival rates

The first thing we have to determine is the number of patients arriving to the IEP, both via the IEP and as external referrals. For each of these groups we have to determine the number of patients per hour using the method as described in Section 4.2.1.

This means that as a basis, we have to determine for every time interval the values for $\alpha^I_{h,d}$ and $\alpha^E_{h,d}$. Also we have to determine the day factors β^I_d and β^E_d for all days d = 1,…,7 and the week factors γ^I_w and γ^E_w for all weeks w = 1,…,52

In the next section, we start with the IEP arrivals.

5.1.1 IEP Arrivals

To determine the values for $\alpha^I_{h,d}$, β^I_d and γ^I_w we look at historic data with respect to received phone calls and arriving self-referrals in the period from 14-4-2010 until 13-4-2011: one year after opening the IEP.

First, we are going to determine the value of $\alpha^I_{h,d}$, per time interval. Since we assumed that there is no difference in the pattern of busy and quit hours between the weekdays from Monday to Friday, it is sufficient to use the same average $\alpha^I_{h,d}$, per hour for all weekdays. For Saturday and Sunday we have 24 separate intervals, leading to a total amount of 2 x 24 + 16 = 64 hourly intervals for which to calculate the average number of arriving patients. For the weekdays we calculate the average number of patients that arrive per hour over all times this hour occurred during the year (5*52). For the hours on Saturday and Sunday we each have 52 values to determine the average over. The resulting values for $\alpha^I_{h,d}$, can be found in Appendix B.

The next step is to determine the day factor β^I_d for every weekday. In order to do this we have to determine how busy every weekday is in comparison to the other days in the same week: the activity factor of that specific day. We calculated for all 52 weeks the 5 activity factors of the days. After this we determined the average activity factor per weekday over the 52 weeks. Since the results were very close, we performed two sample t-tests with a 95% confidence interval, comparing the values of every weekday with all other weekdays. This way we can determine whether it is possible that the 52 activity factors of one weekday could have the same underlying distribution as the factors of another weekday. The results can be found in Table 9.

Table 9: IEP Arrivals: Two sample t-tests comparing the distributions of patient numbers per weekday

Two-sample t-test with 95% confidence interval			
	P-value	Lower Bound	Upper Bound
Mon-Tues	0,368	-0,0214	0,0571
Mon-Wed	0,718	-0,0313	0,0452
Mon-Thu	0,078	-0,0041	0,0755
Mon-Fri	*0,000*	*-0,1609*	*-0,0769*
Tue-Wed	0,589	-0,0509	0,029
Tue-Thu	0,395	-0,0236	0,0593
Tue-Fri	*0,000*	*-0,1804*	*-0,0932*
Wed-Thu	0,163	-0,0118	0,0693
Wed-Fri	*0,000*	*-0,1686*	*-0,0832*
Thu-Fri	*0,000*	*-0,1987*	*-0,1105*

From these results, we see that when we compare the Friday to any other day, we get a small p value and a confidence interval that does not contain zero. This means that Friday has a different underlying distribution, whereas the number of patients on Monday to Thursday are distributed the same. Subsequently, we used the software package 'Minitab' to fit the distributions for drawing the day factors. Therefore, we tested the historic values to the Normal, Lognormal, Gamma, Exponential, and Weibull distribution, using the Anderson-Darling statistic. According to this analysis, the best fitting distributions with the historic data are the normal and lognormal distributions as given in Table 10. The other results of the Minitab data analysis can be found in Appendix B.

Table 10: Day factor distributions of the IEP arrivals

Weekday	*Distribution*	*Parameters*	
Mon-Thu	Normal	Mean	0,9736
		Variance	0,0103
		Standard Dev	0,1016
Fri	Lognormal	Location	0,097
		Scale	0,1019
		Mean	1,108
		Variance	0,013
		Standard Dev	0,116

The last factors we have to determine are the week factors γ_w^I, that mimic seasonal effects. To do this, we calculate per week the total number of patients arriving on Monday to Friday. The reason for not including the weekend days is that the deviating level of activity in the weekends is already taken into account by using different values for $\alpha_{h,d}^I$. The numbers of patients per week are then compared to the average number of patients per week throughout the year, to determine which weeks were busier than others. This is done by calculating the week factor per week by dividing the amount for that week by the average amount. This resulted in the following graph (Figure 6).

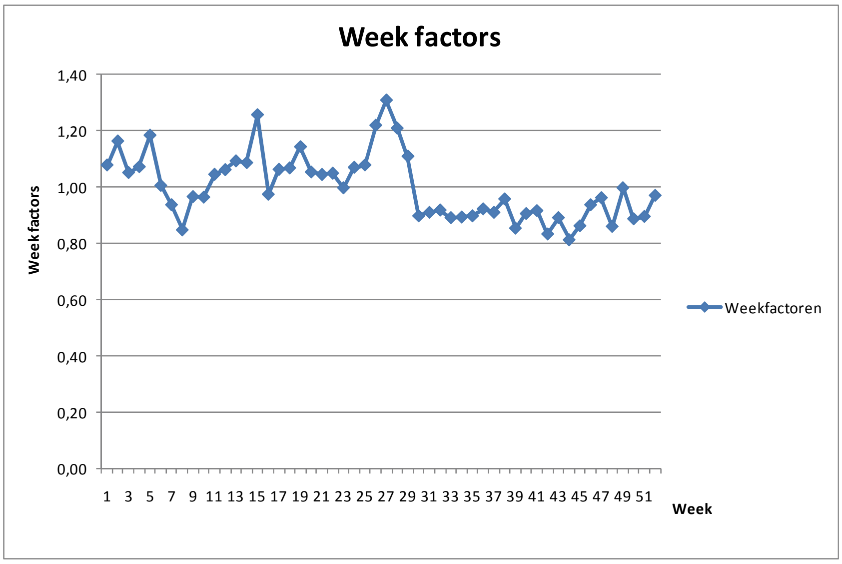

Figure 6: Historical week factors for IEP Arrivals

From Figure 6 we can see clearly that the distribution in the first part of the year is different than in the second part of the year. Up till week 29, the week factors have more fluctuation and a higher average then from week 30 to 52. Therefore we decided to determine separate distributions for both parts of the year. We used Minitab software to find the distributions which results with the best fit (Table 11).

Table 11: Best fitting distributions for the week factors for IEP Arrivals

Week	*Distribution*	*Parameters*	
1 - 29	Lognormal	Location	0,0693
		Scale	0,0915
		Mean	1,076
		Variance	0,010
		Standard Dev	0,098
30 - 52	Lognormal	Location	-0,1019
		Scale	0,0481
		Mean	0,904
		Variance	0,002
		Standard Dev	0,043

Now we have determined the underlying distributions, we can let the model draw a week factor when a new week begins and a day factor at the beginning of each day. When a new hour starts, the historic average number of patients in that hour $\alpha^{I}_{h,d}$ can be found and will be multiplied with the drawn factors, to get the parameter λh,d,w.. Using the Poisson distribution, the number of patients that need to be created in that hour can be determined. The arrivals that were simulated using this approach, will be validated in Chapter 6.

Since the IEP arrivals have other parameters than the external ED arrivals, we are now going to perform the same analysis on historic data from the ED.

5.1.2 External ED arrivals

Using the same approach as for the IEP arrivals, we start with determining the values for $\alpha^{E}_{h,d}$. for each time interval for the arrivals of the externally referrer patients. For this analysis we use data from the period of 14-4-2010 until 13-4-2011. The values of $\alpha^{E}_{h,d}$. for the external ED arrivals can be found in Appendix C.

When analyzing the activity factors per weekday for the ED arrivals, again we found very similar average values for the different days. So, for these values too, two sample t-tests were performed to compare every two weekdays with each other. The results can be found in Table 12.

Table 12: External ED Arrivals: Two sample t-tests comparing distributions of patient numbers per weekday

Two-sample t-test with 95% confidence interval			
	P-value	Lower Bound	Upper Bound
Mon-Tues	0,030	0,0182	0,3504
Mon-Wed	0,016	0,0383	0,3687
Mon-Thu	0,022	0,0312	0,3938
Mon-Fri	*0,165*	*-0,0553*	*0,32*
Tue-Wed	0,803	-0,1325	0,1708
Tue-Thu	0,742	-0,141	0,1973
Tue-Fri	*0,559*	*-0,2279*	*0,124*
Wed-Thu	0,916	-0,1593	0,1772
Wed-Fri	*0,422*	*-0,2463*	*0,1041*
Thu-Fri	*0,406*	*-0,2704*	*0,1102*

This time we see that Monday is the day with a different distribution. Therefore, we are going to find one distribution for the day factors for Tuesday to Friday and one for Monday. Again, we use Minitab software to do this, giving the following results (Table 13).

Table 13: Day factor distributions of the external ED arrivals

Weekday	*Distribution*	*Parameters*	
Mon	Weibull	Shape	2,684
		Scale	1,288
		Mean	1,147
		Variance	0,211
		Standard Dev	0,459
Tue - Fri	Weibull	Shape	2,322
		Scale	1,088
		Mean	0,963
		Variance	0,194
		Standard Dev	0,440

Similar to the IEP arrival week factors, the ED week factors are also calculate by comparing the number of patients on weekdays in a certain week to the average total number of patients arriving on weekdays (Figure 7).

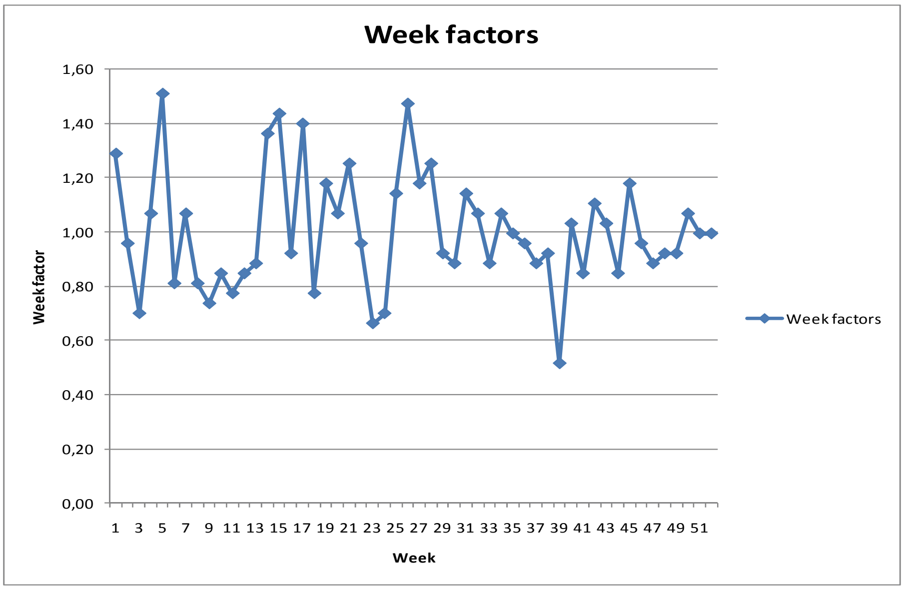

Figure 7: Historical week factors of the external ED arrivals

We see that the number of arrivals per week varies much across the year, but not with a recognizable pattern. Therefore we decided it is sufficient to determine one distribution from which the week factors can be drawn for the entire year (Table 14). To be able to reflect the fluctuations as seen in the historic data the used distribution will have a large variance.

Table 14: Best fitting distributions for the week factors for external ED Arrivals

Week	*Distribution*	*Parameters*	
1 - 52	Lognormal	Location	-0,0224
		Scale	0,2152
		Mean	1,000
		Variance	0,045
		Standard Dev	0,213

With the distributions determined in Sections 5.1.1 and 5.1.2, we can now mimic the variability in patient arrivals. For each hour, the simulation model will use the distributions found to set the number of patients that need to be created. The next step is to set the variables with respect to for example urgency and number of diagnostic tests for each created patient. Therefore we have to determine the probabilities of being assigned every possible variable value. In the next section, we will determine these probabilities, following the sequence in which variables get assigned to a patient according to the modeling steps presented in Section 4.5, starting with determining the GP post urgency.

5.2 Time dependent GP post urgencies

In Chapter 4, we assumed that the urgencies of patients at the GP post are time dependent. This assumption is based on the experience of staff members. At this point, we have to check whether this assumption is correct. We also have to determine the input data for the simulation model in terms of the probability per urgency category for each time interval. To do this, we are going to analyze data from one year after the implementation of the IEP. We divide the IEP visiting hours in intervals of one hour. For each hour we take the total number of patients that arrived historically in that hour and group them according to their assigned GP post urgency. Then we calculate the percentage per category. The results can be found in Appendix D. The analysis confirms the assumption we made: the distribution of patients over the categories of urgency differs over time. We see from the past year that patients that arrive at night do have a slightly higher probability of having high urgency than patients that arrive during the day. The found percentages per time interval will be used as input data for the simulation model.

5.3 Analysis Patient routes through the IEP

The next variable to set for each IEP patient is which path A the patient follows. By examining the processes at the IEP, see Section 4.1, we came to eight paths that can be taken through the IEP (Table 2). At this stage we have to determine what the probabilities are that a patient takes a certain path. Therefore we look at historic data from the databases of the GP post and the ED. Self-referrals have not been registered separately until November 22 2010, so we use data from December 2010 to July 2011 for our analysis. In this case there is no harm in not using data from an entire year, since we do not assume the patient routes being time dependent directly. The relation between time and patient route that is found in reality is reflected in the simulation model indirectly, through the variable GP urgency.

5.3.1. Determining Path A

From the GP post data, we can directly derive the division of patients over the paths A1 to A8 from the registered data. In Section 4.2.2, we assumed that the probability of patients taking a certain path A, depends on the GP post urgency that is assigned to that patient. The reasoning behind this assumption is that more urgent patients are more likely to get a consult or get referred to the ED. In the previous section we derived that the GP post urgency of a patient is depending on the time of arrival. Now we are going to determine per urgency category the distribution over the different paths. We do this by determining for each month from December 2010 till July 2011 the total number of patients per urgency category. Subsequently we calculate per category the percentage of patients per path. Finally we calculated the average percentage per category, per path over the eight months (Appendix E). The division over the different paths, per urgency category is given in Figure 8.

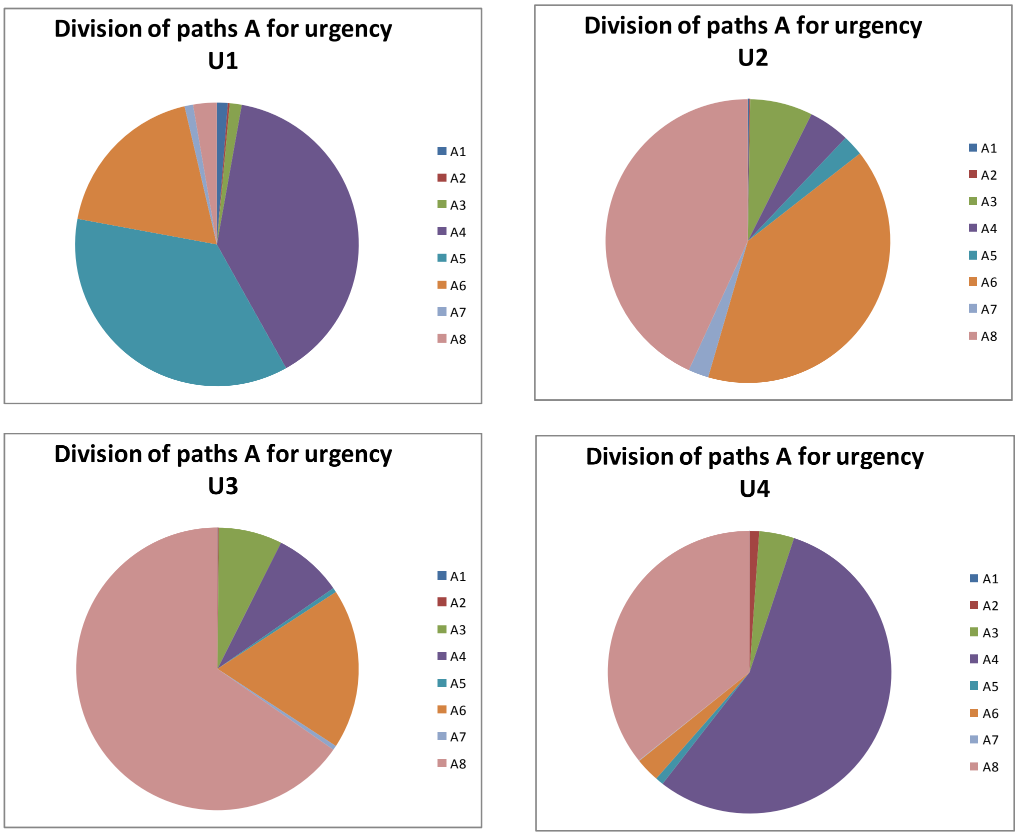

Figure 8: Division of patients over the paths A1 to A8, per urgency category

From Figure 8, we see that the division of patients across the different paths differs a lot from one urgency category to the other. From this we conclude that our assumption, that the probability of a patient following a certain path A depends on its GP post urgency, is correct. The percentages as given in Appendix E will be used as input for the simulation model.

5.3.2. Determining Path B

As seen in the previous section, the distribution of patients for path A can easily be determined. For all patients, we can determine directly whether they went home, got a consultation, or went directly to the ED. However, there is no data registered at the GP post with respect to the results of a consultation. This means we know how many patients got a consultation, but we do not know what the outcome of the consultations was. Therefore we have to derive this information indirectly by looking at connected activities for which data is available. In this case we can use the data from the X-ray division and the ED. For each patient at the ED their origin is registered. Unfortunately the categories of origins cannot be directly linked to the paths through the GP post. Therefore we have to make assumptions about which ED origin category can be linked to which path A and B. A visual representation of this problem with data linking can be found in Figure 9. In this figure we see paths through the GP post and the different registration of origins from the ED. For some of the paths we have information on the number of patients taking that path from the GP post data, X-ray data, or ED data. For the paths that are indicated with 'Arrow' we have to determine the number of patients indirectly. The question mark indicates the problem in linking the different origin categories as registered by the ED with the paths leading to the ED through the GP post and externally.

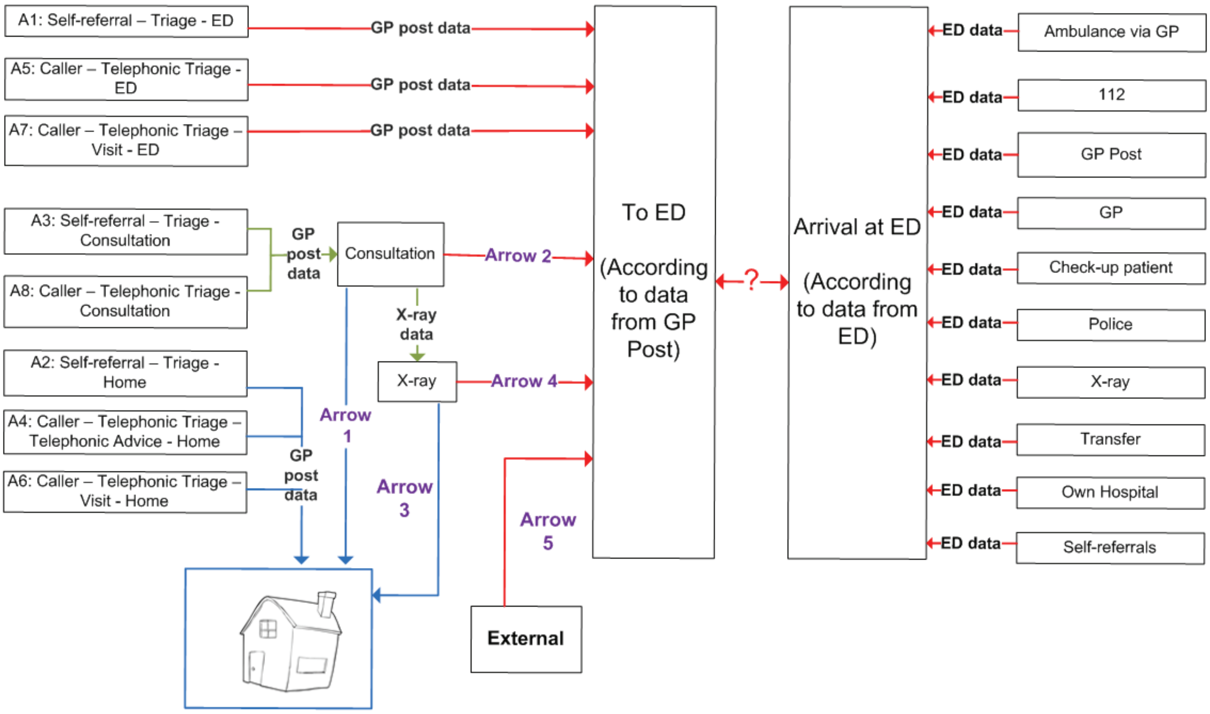

Figure 9: Visual representation of the problem with linking data GP post to data ED

As an example on how we link the GP post data to that of the ED, using data from connected activities, we are going to look at the data of the month December 2010 (outside office hours).

The total number of contacts via phone or self-referrals is 4285. These patients can be categorized into the paths A1 to A8 using the registered data from the GP post. The results can be found in Table 15.

Table 15: Path A and the number of patients per path for December 2010

A1	Self-referral - Triage - ED	5
A2	Self-referral - Triage - Home	20
A3	Self-referral - Triage - Consultation at GP post	223
A4	Caller - Telephonic Triage - Telephonic Advice - Home	1687
A5	Caller - Telephonic Triage - Telephonic Advice - ED	53
A6	Caller - Telephonic Triage - Visit - Home	493
A7	Caller - Telephonic Triage - Visit - ED	20
A8	Caller - Telephonic Triage - Consultation at GP post	1784

This means that a total of 2200 patients went home (or stayed at home) after their contact with the IEP (path A2, A4 and A6). A total of 2007 patients got an appointment for a consultation (path A3 and A8) and 78 were directly referred to the ED. From the 2007 patients that had a consultation, there is no registration on which path B they followed after the consultation. These paths B correspond to the arrows in Figure 9 as indicated in Table 16*: Possibilities for path B, the number of patients for December cannot be determined directly*

Table 16: Possibilities for path B, the number of patients for December cannot be determined directly

	Path	*Indicated in Figure 9 by:*
B1	Consultation at GP post - Home	Arrow 1
B2	Consultation at GP post - X-ray - Follow-up Consultation GP - Home	Arrow 3
B3	Consultation at GP post - X-ray - ED	Arrow 4
B4	Consultation at GP post - ED	Arrow 2

From the GP post data we cannot derive any information on the number of patients per path B. However it is possible to get data from the X-ray department on the total number of patients that got an X-ray ordered by a GP outside office hours (so path B2 + B3). In December, this amount was 330 patients. To find out how many of these 330 patients have gone to the ED (path B3) and how many went home (B2), we have to look at the data as registered by the ED.

The total number of arrivals at the ED in December was 704 patients. At this point we do not know which patients were external arrivals and how many arrived through the IEP. We have to derive this information from the origins as registered at the ED (Table 17). When analyzing these origins, some strange aspects stand out. For example, 106 patients have been registered as self-referrals. But this data stems from outside office hours, when the IEP is opened, making it unable for self-referrals to end up at the ED without going through the GP post first. Also, 73 patients are registered as coming from the GP, and 141 as coming from the GP post. But since the GP post replaces the regular GP offices outside office hours, it would not be possible to be referred to the ED by a GP outside of the GP post. Therefore we assume that the patients categorized as referred by the GP, are in fact referred by the GP post. Since the amount of self-referrals seems to originate from a registration error, we decide to divide the amount of self-referrals relatively among the other categories. This leads to the revised data as given in Table 17**.**

Table 17: Origin categories from ED data, with the number of patients per origin as registered in December 2010

Category	*Original data*	*Revised data*
112	90	106
Ambulance via GP	66	78
GP Post	141	166
Check-up patients	9	11
Own hospital	76	89
GP	73	86
Police	6	7
X-ray	137	161
Transfers	0	0
Self-referrals	106	0

For each of the remaining origins we now have to determine whether they are considered to be referred externally or through the IEP (in order to reveal the number of patients at arrow 5 in Figure 9). *The clear external categories are '112', 'Check up patients', 'Own hospital' (policlinic patients), 'Police' and 'Transfers'. The patients that arrive through the IEP for sure are those from the categories 'GP post', 'GP' and 'X-ray'.* With respect to the category Ambulance via GP, there are some doubts. One possible scenario for these patients is that they have visited their own GP during office hours, an ambulance was ordered and the ambulance arrived at the hospital outside office hours. This would make the patients externally referred. The other possibility is that the patients called the IEP outside office hours, a GP was send for a visit and the GP decided to call for an ambulance. In this case the patients would be categorized as arriving though the IEP. *The compromise in this case is to split the number of patients with the origin 'Ambulance via GP'. The number of patients that, according to the data of the GP post, followed path A7 (Caller – Telephonic Triage – Visit – ED) are considered arrivals through the IEP. The remainder is considered as external arrivals.*

When applying the distribution as explained above to the data of December 2010, we get the following division:

- Total number of external arrivals at the ED: 271 (arrow 5, Figure *10*9)
- Total number of patients arriving at the ED through the IEP: 433

From the 433 patients arriving through the IEP, we know from the GP post database that 78 were directly referred (paths A1, A5 and A7). We also know from the X-ray data that 330 patients were directed to the X-ray from the GP post. According to the ED data, 161 of them were forwarded to the ED (arrow 4 in *Figure 1*Figure 9, path B3). This means that 330 – 161 = 169 were send home after making the X-ray with an advice from a GP at the GP post (arrow 3 in Figure 9, path B2). Then, the last fraction of patients arriving at the ED is the number of patients referred directly from consult to the ED (arrow 2 in Figure 9, path B4). For December this amount was 433 – 78 – 161 = 194.

With a total of 2007 patients getting a consultation, 330 being send to X-ray, and 194 being referred directly to the ED, it leaves an amount of 1483 patients that were send directly home after consultation (arrow 1 in Figure 9, path B1). With this analysis we have managed to identify the number of patients following the paths B1 to B4. The results of this analysis are given in Figure 10.

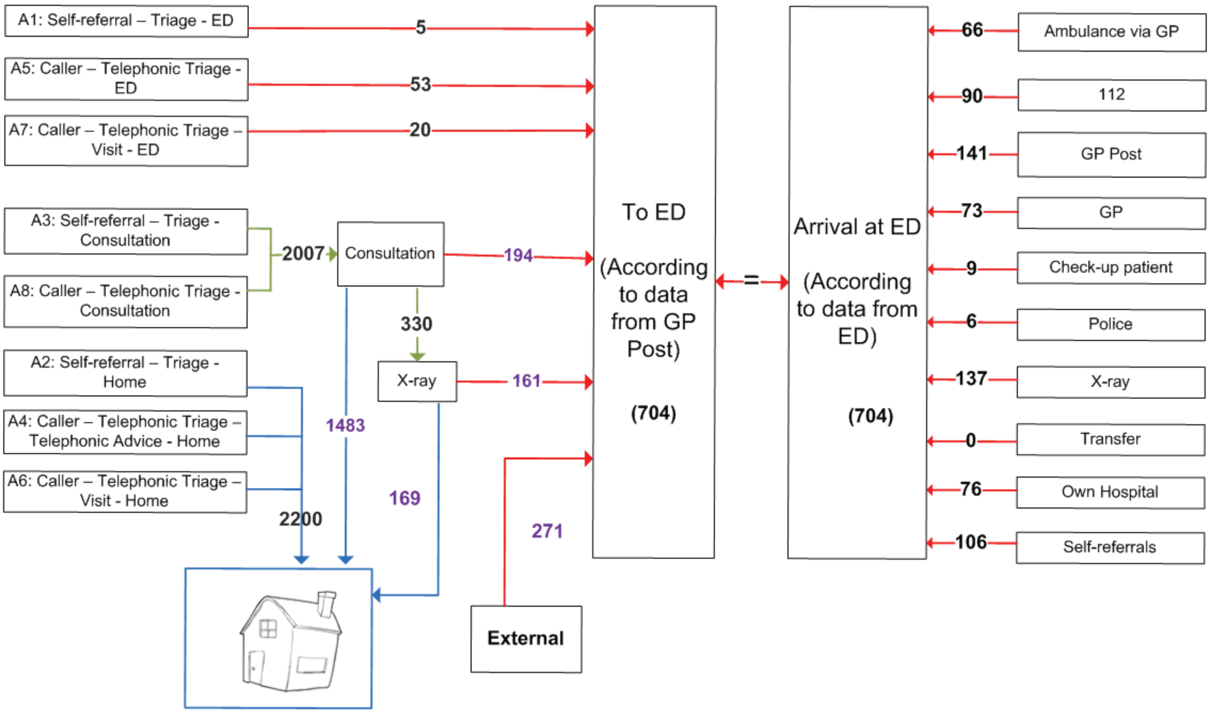

Figure 10: Linking of Data GP post to data ED

By extending this analysis to the other months, we determine the average percentage of patients traveling a certain path B (Table 18). The possibility of choosing a path in the model is only determined by the historical fractions of patients taking that path and is independent of other variables.

Table 18: Probabilities for patient route B1 to B4

Path	*Average percentage of patients*
B1	0,7653
B2	0,0883
B3	0,0567
B4	0,0896

At this point we know how many patients eventually end up at the ED through the IEP. Once the patients arrive at the ED, first there urgency has to be re-determined because of the different triage system. Also for the patients that arrive external, ED urgency must be assigned.

5.4 ED Urgencies

In Section 4.2.3, we assumed that the ED urgency can be determined in two ways: For the patients that are referred to the ED by external sources, we assume the urgency to be time dependent. The patients that arrive through the IEP already got a GP post urgency assigned, which can be used to determine the ED urgency.

To analyze the ED urgencies of external arrivals we use the same approach as with the time dependent GP post urgencies (see Section 5.2). We use data from one year after opening of the IEP and summarized the patients per category per hour. However the external arrivals involve much less patients per hour than the arrivals at the GP post. To base the percentages on a representative number of patients per interval, we decide to broaden the intervals. This prevents us from modeling coincidental fluctuations that occur from hour to hour as variance. The time intervals for Monday to Friday are now: 0:00 – 3:59, 4:00 – 7:59, 17:00-19:59 and 20:00-23:59. For Saturday and Sunday we split the day into 6 intervals of four hours (0:00-3:59, 4:00-7:59, 8:00-11:59, 12:00-15:59, 16:00-19:59 and 20:00-23:59). For each of these intervals we calculate the percentage of patients in each urgency category. The results can be found in Appendix F. We see the percentages of the patients per urgency category fluctuate over time. This confirms the assumed dependency between time and assigned ED urgency for external arrivals. The found percentages per category also serve as input data for the simulation model.

For the patients that arrive through the IEP, we assume a relation between the GP post urgencies and ED urgencies. To check this assumption, we perform a data analysis on data from November 2010 – June 2011. In this analysis the database of the GP post is linked to that of the ED and patients that were in both databases were singled out. This led to a total amount of 211 patients. Then, the GP post urgency of these patients was compared to their ED urgency. The relationship between the urgency categories is depicted in Figure 11 .

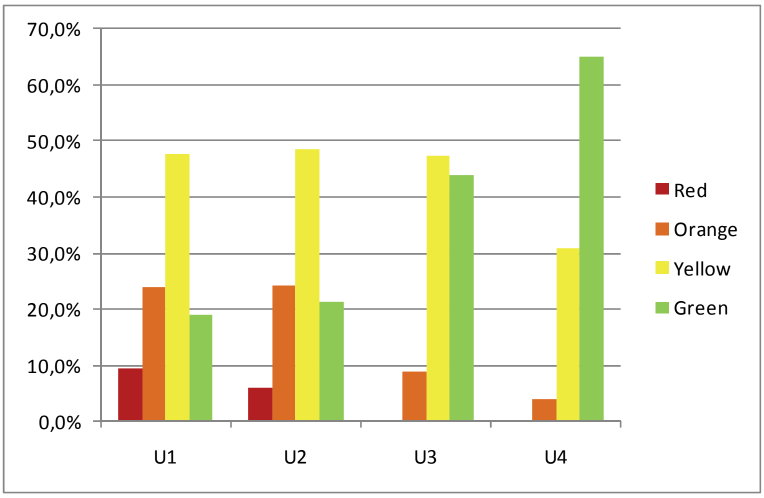

Figure 11: GP post urgency to ED urgency

As we can see from Figure 11, there seems to be a logical relation between GP post urgency and ED urgency. The patients with GP post urgency U1 have the highest probability of being assigned urgency 'red' at the ED, compared to the other GP post urgencies. Also we see that patients, who are categorized as least urgent (U4) at the GP post, have a large probability of being categorized in the least urgent category 'green'. This confirms our assumption that there is a relation between GP post urgency and ED urgency. One peculiar fact we can see from this data, is that from all patients referred to the ED through the IEP in the period from Nov 2010 till June 2011, no one was assigned the urgency category 'Blue". The numerical results of this analysis can be found in Appendix G.

5.5 Time dependent Simulation Groups

When a patient arrives at the ED, not only his urgency has to be determined, but, as stated in Section 4.2.3, patients also need to be categorized into simulation groups according to their 'Diagnosis Related Groups'. We assume that the distribution into groups is time dependent. Now we are going to analyze the historic data to check whether that assumption is correct. Therefore we look at all patients that arrived at the ED, outside office hours, in the period one year after the IEP was opened. All patients are grouped into the simulation groups according to their specialty and code for diagnosis (Table 19).

Table 19: Simulation groups and the percentage of patients per group in the period from 14-4-2010 until 13-04-2011

Nr	*Group*	*Diagnosis code*	*Percentage of patients*
1	Surgery - Trauma - Fracture	201 - 269	28,6%
2	Surgery - Trauma - Wound	280, 281, 282	4,4%
3	Surgery - Trauma - Rest	279 - 279 + 283 - 288	10,3%
4	Surgery - Abdomen	111 - 129	7,2%
5	Surgery - Rest	All remaining surgical patients	7,1%
6	Neurological - Stroke	All neurological patients with a code starting with 11..	3,8%
7	Pulmonary medicine	All patients from the specialty pulmonary medicine	5,8%
8	Internal medicine	All patients from the specialty internal medicine	13,7%
9	Cutting specialties	All patients from the specialties: Gyneacology, Ear, nose and throat, Ophthalmology, Orthopedics, Plastics and Urology	10,0%
10	Contemplative specialties	All remaining patients from all remaining specialties	9,1%

To get a distribution that is based on a representative number of patients, we use time intervals of multiple hours. This way we prevent coincidental fluctuations per hour to be modeled as variation. The time intervals we choose are the same as for modeling the time dependent ED urgencies (see Section 5.4). Per time interval we calculate the total number of patients per group over the entire period. Subsequently, this amount is converted to a percentage per group relative to the total number of patients arriving in that interval. The results can be found in Appendix H. The results show that the division of patients over simulation groups varies over time and therefore confirm our assumptions of time dependent simulation groups. The results are used as input data for the simulation model, to determine the probability for a patient of being categorized in a certain simulation group.

5.6 Diagnostics per Simulation group

Once we have assigned every patient to a simulation group, based on his urgency, the next step is to determine the need for diagnostic tests. Therefore we are going to calculate the probabilities involved with diagnostics: what type of diagnostics tests does a patient need and how many? As stated in Section 4.2.3., there are five types of diagnostic tests that are included in the simulation model: Labs, X-rays, CT scans, ECGs and ultrasounds. The probability of a patient needing one type of test is assumed to be independent of whether he also needs one of the other types of tests. This means that we are going to do five independent draws to determine for every type of test individually whether the patient needs it. To determine the probability of needing a test we are going to look at the number of people that needed that test in the period one year after opening the IEP. Since we assume that the probabilities of needing a type of test depend on the simulation group, we sort the patients by simulation group. With respect to lab analysis as diagnostic test, there is no data available on how many patients needed this type of diagnostic test. Therefore we use estimates for the percentage of patients needing lab per simulation group. These estimates are provided by the involved stakeholders. Subsequently we divide the total number of tests taken by the number of patients taking that test to get the average number of tests needed per patient. For lab analysis we assume that every patient gets a maximum of one lab analysis. The results can be found in Appendix I and show that the probability of needing a type of test can differ much from one simulation group to another. From this we conclude that our assumption on a relation between simulation group and the need for diagnostic tests is correct, based upon the historic data and the estimates of the stakeholders. The probabilities per test per simulation group as given in Appendix I, are used as input data for the simulation model.

5.7 Exit destination depending on simulation group

The last dependency assumption that we need to check is the relationship between the simulation group of a patient and its exit destination. The assumption of dependency is based upon the experience that patients with certain symptoms have more chance of being admitted or transferred than patients from other simulation groups. For this analysis we also look at historic data from one year after the opening of the IEP. In the database there are several categories for the destination of patients. For this model we are only interested in the general destination, being whether a patient has to stay in the hospital (admission), was transferred to another hospital, or left the hospital. This is important to determine for the model since patients that are waiting for admission or transfer, still occupy an ED room while waiting. We have to determine the probability for each simulation group that a patient is going to be admitted or transferred. Therefore we group each destination category from the dataset into one of the three options (Table 20).

Table 20: Exit destinations after treatment at ED

Destination Category	***Option***
Department own hospital	*Admission*
Centre for burn victims	*Transfer*
Morgue	*Exit without waiting*
Policlinic return	*Exit without waiting*
Home	*Exit without waiting*
Transfer	*Transfer*
Trauma Centre	*Transfer*
Left against medical advice	*Exit without waiting*
Other hospital	*Transfer*

When we divide the patients from one year after opening the IEP per simulation group over the exit options we get the following results (Figure 12).

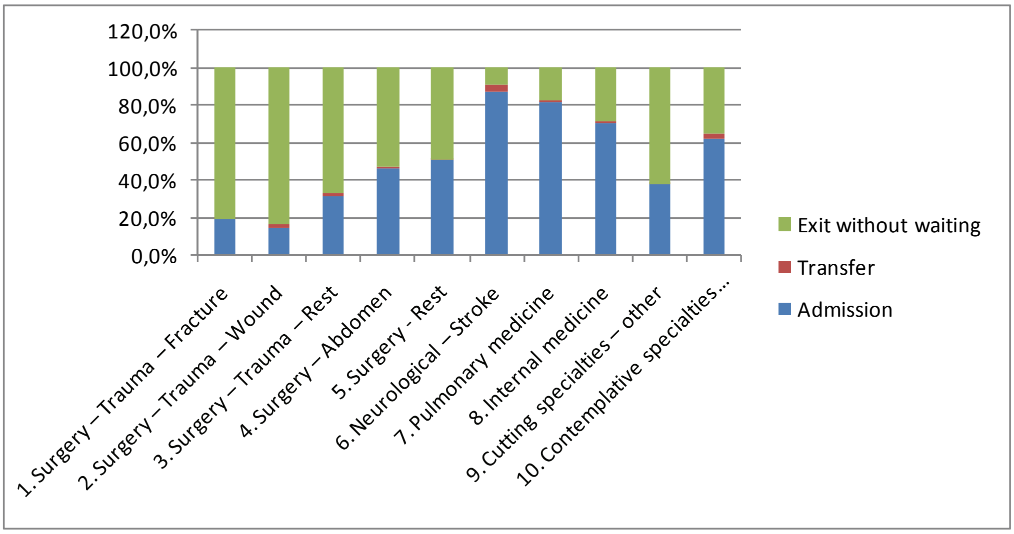

Figure 12: Exit destinations per Simulation group

This graph supports our assumption that the probability for a patient of having a certain exit destination is strongly related to the simulation group of the patient. The associated percentages can be found in Appendix J and will be used in the simulation model.

5.8 Personnel availability

In Section 4.3.1, we introduced the different types of personnel that will be included in the simulation model. Now we have to determine how many staff members of each type are present in each of the time intervals. In order to get this information, we asked some of the involved stakeholders to fill in tables with the amount of personnel at each time interval. These tables can be found in Appendix K. From these tables we created working rosters for the staff in the model. These rosters are roughly based on the roster used in reality, but some adjustments were made to increase usability for the model. For example, in the model all shifts starts and end on whole hours. We also shifted the rosters in such a way that on each day a change of shifts takes place at 0:00 hour, along with the starting of the new day. The rosters resulting from this approach can be found in Appendix L.

The exceptional staff members are the medical specialists and diagnostic nurses. Both types are not always present at the IEP, but are called when needed. For medical specialists as well as diagnostic nurses we assume an infinite amount of personnel available. This means that they are always available when they are needed to perform a task. However, as stated in Section 4.3.1, we have to take into account that these types of personnel need some time to get to the ED, because of travel time from their external locations and the fact that they might need to finish their work there first.

In Section 4.3.1, we assumed that the waiting time for a medical specialist depends on the ED urgency of the patient for which the specialist is needed. Unfortunately there is no data available with respect to the number of times a specialist was called per urgency category and the amount of time it took him to get there. Therefore we must make assumption based on the estimation of involved stakeholders. Table 21 shows the assumptions we made on the probability that a medical specialist is needed and the amount of time until arrival of the specialist per urgency category.

Table 21: Need and delay on arrival for a specialist, per urgency category based on assumptions of involved stakeholders

	Probability of needing specialist	*Time until arrival specialist*
Red	98%	5 min
Orange	75%	15 min
Yellow	30%	60 min
Green	10%	60 min
Blue	2%	90 min

In Section 4.3.1, we stated that diagnostic nurses are needed for three out of five diagnostic tests, being X-ray, ultrasound and CT scan. For each type of test, a different type of nurse is needed. Since these nurses are usually working elsewhere in the hospital, it can take them some time before they finished their previous task and are able to come to the ED. We assume this time is different every time and can be described by a probability distribution. Unfortunately, no data is available on the amount of time it takes different types of diagnostic nurses to get to the ED. Therefore, we have to determine the probability distribution of the waiting time until arrival per type of diagnostic nurse, by using estimates. The easiest way to get an idea on the shape and place of the distributions is to let involved stakeholders give estimates of the minimal time, the maximal time and the standard time till arrival. The minimal time is defined as the minimal time it takes 97.5% of the diagnostic nurses to get to the ED (per type). In the same way the maximal time gives the time in which 97,5% manages to get to the ED. The standard time is the time it takes most nurses to get there. This standard time is not always the same as the average between the minimum and the maximum. This is because the minimum can never be less than 0 minutes, but occasional long waiting times can skew the probability distribution to the right. The estimates as given by the involved stakeholders can be found in Table 22.

Table 22: Estimates on minimal, maximal and standard time till the arrival of diagnostic nurses

	min	*max*	*standard*
Time until arrival DN X-ray	5	90	15
Time until arrival DN Echo	10	60	30
Time until arrical DN CT scan	0	30	10

The estimates as shown in Table 22, all indicate a distribution that is skewed to the right, as expected. This indicates the times until arrival can be defined by Gamma distributions. Subsequently we used the Excel solver to determine the correct parameter values to get Gamma distributions with the minima and maxima as described in Table 22. Appendix M gives an overview of the distributions of all processing times and their parameter values as put into in the simulation model.

5.9 Processing times

In the previous section, we determined the underlying probability distributions for the waiting time until the arrival of diagnostic nurses. At this point we have to do the same thing for all other processing steps that occur on the IEP. This does not only involve all tasks as described in Table 5, but also for example necessary travel times to visit patients. Traveling times from one location to the other within the IEP are assumed to be non significant, and therefore are not included in the simulation model. In the databases of the GP post and ED, some information is registered with respect to the starting time of certain procedures. However this does not concern all processing steps, and there is a great amount of doubt among the involved stakeholders with respect to the reliability of this data. Therefore, we decided to base the input for the processing times in the simulation model on estimates of involved stakeholders instead of on the available historic data. Similar to the waiting times for arrival in Section 5.8, we ask the involved stakeholders to give us estimations of minimal, maximal and standard duration times for each step that occurs in the simulation model. The results can be found in Table 23. From the estimates of the stakeholders we determined for every process step the distribution which we can use to mimic the processing times. For process steps with the same minimal, standard and maximum time, the processing times are deterministic. For processes for which the estimates suggest a symmetrical distribution, we use the Normal distribution. For all process steps were the estimates point to a asymmetrical distribution, the distribution is skewed to the right. Therefore we decide to approach these processing times by using a Gamma distribution. By using the Excel solver, we determined for every distribution the correct parameter values to put into the simulation model, such that a maximum of 2,5% of the processing times are smaller than the minimal duration and a maximum of 2,5 % is larger than the maximum duration, as given in Table 23. An overview of the parameters that are used in the simulation model, can be found in Appendix M.

Table 23: Estimated minimal, maximal and standard processing times

	Task	*Minimal duration*	*Maximal duration*	*Standard duration*	*Distribution*
GP post	*Telephonic triage*	2	15	4	Gamma
	Triage GP post	4	10	5	Gamma
	Consultation at GP post	10	30	10	Gamma
	Traveltime to Visits	5	39	22	Normal
	Duration Visits	5	60	17	Gamma
ED	*Triage ED*	2	10	5	Gamma
	Patient history, first time	5	15	10	Gamma
	Patient history, second time	5	30	15	Gamma
Diagnostic tests	*Perform Ultrasound*	10	30	15	Gamma
	Perform Lab	5	15	10	Normal
	Lab analysis: short 30 min	30	30	30	Deterministic
	Lab analysis: long 60 min	60	60	60	Deterministic
	Waiting for Diagnostic Nurse ultrasound	10	60	30	Gamma
	Waiting for Diagnostic Nurse x-ray	5	90	15	Gamma
	Waiting for Diagnostic Nurse CT scan	0	30	10	Gamma
	Perform X-ray (per test)	5	5	5	Deterministic
	Perform CT scan (per scan)	20	20	20	Deterministic
	Perform ECG	5	10	7,5	Normal
Treatment ED (duration dependent on Simulation Group of the patient)	*S1 Casting (by ED Nurse or PA)*	10	90	30	Gamma
	S2 Treatment by resident	10	40	20	Gamma
	S2 Treatment by medical specialist	0	40	10	Gamma
	S3 Treatment by resident	10	30	15	Gamma
	S3 Treatment by medical specialist	0	30	10	Gamma
	S4Treatment by resident	10	20	15	Normal
	S4 Treatment by medical specialist	0	20	10	Normal
	S5 Treatment by resident	10	20	15	Normal
	S5 Treatment by medical specialist	0	20	5	Gamma
	S6 Treatment by resident	10	30	20	Normal
	S6 Treatment by medical specialist	10	30	20	Normal
	S7 Treatment by resident	15	35	25	Normal
	S7 Treatment by medical specialist	0	20	10	Normal
	S8 Treatment by resident	15	45	30	Normal
	S8 Treatment by medical specialist	0	40	20	Normal
	S9 Treatment by resident	10	50	30	Normal
	S9 Treatment by medical specialist	0	30	15	Normal
	S10 Treatment by resident	10	60	30	Gamma
	S10 Treatment by medical specialist	0	60	30	Normal
Exit ED	*Wachten op SEH voor opname*	0	80	20	Gamma
	Wachten op SEH voor overplaatsing	5	120	45	Gamma

One processing step that is not mentioned in Table 23, is ‘waiting for a consultation’. When a patient calls the IEP and he has to come to the IEP for a consultation at the GP post, in reality an appointment time is given based upon his symptoms and urgency. There are also regulations that state for each urgency category within how much time a patient must be seen by a staff member. It is complicated to program the decisions with respect to determining a time for an appointment. In reality many aspects are taken into account, which we cannot include in the model, such as expected number of patients later on the day, amount of stress and anxiety in the patient and experience. Therefore we have to find another way of modeling appointment times.

In reality, when a patient arrives at the IEP at the assigned appointment time, the patient often gets a consultation soon. In the model, we choose not to include appointment times. At the moment a patient enters the hospital, the consultation is placed on a list of tasks to perform. A patient in the waiting room is helped as soon as all necessary resources are available and he has the highest priority of all waiting patients. This means there can be extra delay in the waiting room opposed to the reality. This can be compensated with the amount of time spend by patient waiting at home before coming to the hospital. The way in which we translate the reality to the model can be found in *Table 24*.

Table 24: Modeling appointment times for the IEP

	Regulations	Delay in simulation model
U1	within 15 minutes	comes directly to the IEP
U2	within 60 minutes	15 minutes delay
U3	within 180 minutes	60 minutes delay
U4		180 minutes delay

Chapter 6 Simulation Model

In Chapters 3 and 4, we designed the conceptual model for the IEP. In this chapter, we have translated the conceptual model directly into a computer simulation model. To do this, the program Plant Simulation from Tecnomatix (version 8.2) is used. This is discrete-event simulation tool. First a short description is given of the global structure of the simulation model. Then we look into the verification and validation of the model.

6.1 Global structure of the computer simulation model.

The basis for the simulation model is the map of the IEP. We choose to use the exact layout of the IEP to increase recognizability for the stakeholders and future users. The patients are shown as small figures that move around on the map. Patients are colored orange when their destination (GP post or ED) and urgency are unknown, for example when they call the call centre or walk into the main hall as self-referrals. After triage, they turn blue for destination GP post and red for destination ED. They also get a square marker which shows their urgency. For the GP post U1 = red, U2 = orange, U3 = yellow and U4 = green. We use pictograms to indicate staff members. Each type of staff member has a different color. Separate areas are determined for patients ‘waiting for consult’, ‘waiting for visit’, ‘being visited’ and for staff members ‘being off shift’ or ‘traveling’. This last status is for GPs going on a visit and for medical specialists and diagnostic nurses that are called to the ED. A screenshot of the simulation model can be found in Figure 13.

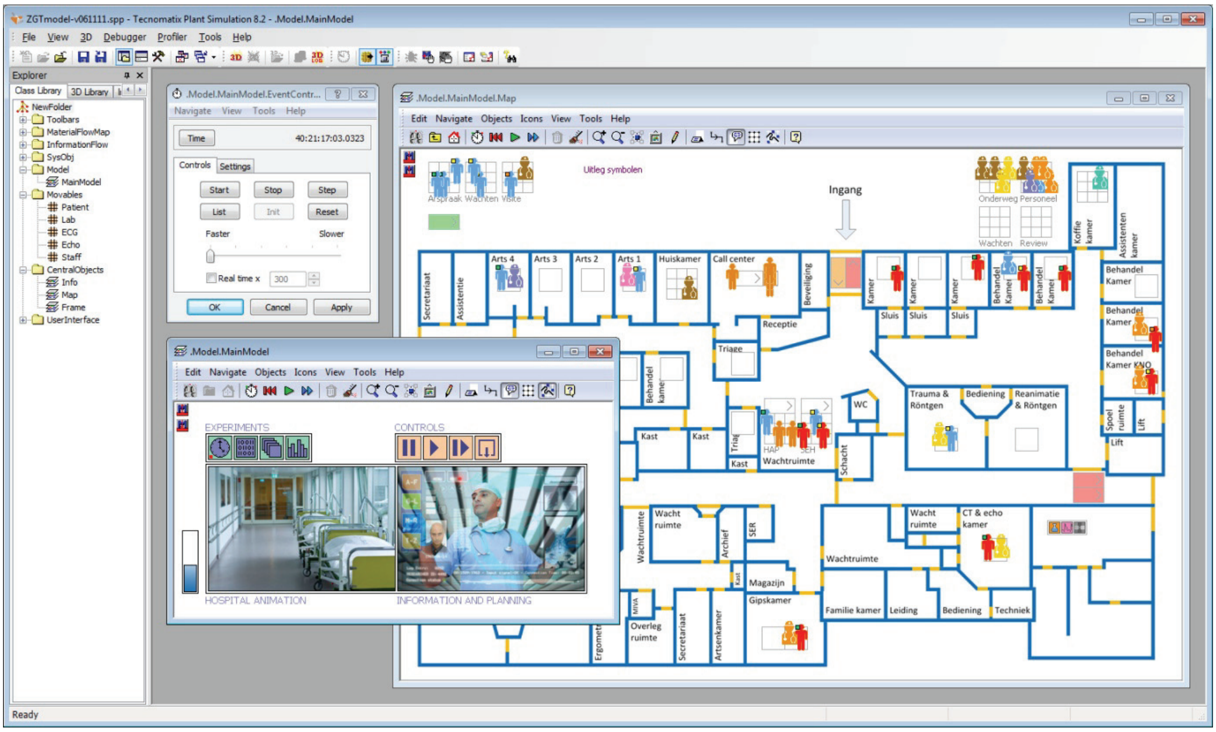

Figure 13: Screenshot of the computer simulation model

In the simulation model, all processing steps are called stages. Since we use discrete-event simulation, we must identify events that trigger other actions. Two of those triggers are ‘begin stage’ and ‘end stage’; the third one is the passing of time in the simulation model. Every time a patient is created to enter the IEP, the first task of that patient is put on the task list. The tasks on this task list are sorted according to the rules for patient prioritizing as stated in Section 4.6, first on urgency, then on amount of time the task is already on the task list. For the first patient on the list for which all necessary resources are available, the next stage is started. When the processing time for the specific stage has expired, that specific task is ended. This means the resources that were being used by that patient can become available again, with exception of the room which in some situations stays assigned to the patient. The release of resources triggers the program to check whether a new stage can begin. The passing of time triggers changes with respect to the availability of personnel. At the moment the shift of a certain staff member ends, the staff member finishes the task he is currently performing and then leaves the IEP. Also, on weekdays the IEP closes at 8:00 in the morning. In the simulation model this means that all patients and staff members leave the system. Patients that were in the middle of a certain processing step do not finish this step. The data of these patients is not included in the registration of performance indicators such as average throughput time.

Normally, for every stage a patient, room and staff member come together. However, with the reviewing of test results from an X-ray, ultrasound or CT scan, the presence of the patient is not necessary. Therefore we create a secondary, offline task list on which review tasks are put, which take place 'behind the scenes' of the IEP. We decide that in prioritizing tasks, an offline task for a patient always has priority over an online task for a patient with the same urgency category and waiting time. This is because most of the review tasks only require a small amount of processing time to perform and otherwise can cause long waiting times. For the laboratory test, analysis can either take 30 or 60 minutes, depending on the simulation group of the patients. Nonetheless, we treat this analysis too as an offline reviewing task with priority over online tasks. This is because lab analysis does not require resources and therefore can start immediately.

All input data we determined in Chapter 5 is entered into the simulation model and random draws are done for each patient to determine the process steps that patient need to go through. As output we register for every created patient the variable settings, such as urgency, paths, and tests needed. At this point it is not yet clear which performance indicators need to be measured. Therefore we decided to register the most common ones: total throughput time and waiting time between subsequent stages. These values can serve as a first step for validating how much the model resemblances reality. During the programming of the model, the structure is deliberately kept generic, in order to increase the possibility of using the simulation model in other situations, similar to this IEP.

Before validating the resemblance to reality, we have to verify whether the simulation model corresponds to the conceptual model that we designed in Chapters 4 and 5.

6.2 Model Verification

In this section, we are going to determine to what extend the final simulation model is a correct translation of the conceptual model we designed.

According to Law (2007), there are several techniques for verifying a simulation model. The first one is to debug the model. For this simulation model, the debugging took place in several iterations during the programming the model. The final simulation model runs without coding errors. The second technique is to "let more than one person review the model"*(Law, 2007)*. This model is designed and programmed in close collaboration with one of the stakeholders from the hospital. Several interim demonstrations were given of the workings of the simulation model. Another technique mentioned in the book of Law, is to run the simulation model and analyze whether the output is correct with respect to the inputted distributions. We performed this analysis for every input distribution for the processing times of the different tasks. To do this, we analyze the results of four simulated years (approximately 240.000 patients) and calculated the minimal, average, and maximal processing time occurring for each process step. We also made a histogram for each process step and compared the location of the top of the histogram with the input standard processing time. For each of the process steps, the output on all of these factors was similar to the estimated as given in *Table 23*.

The last method we used for verifying the simulation model is spending some time watching the animation of the patients moving through the IEP. One obvious difference between the simulation model and the conceptual model is the fact that the staff members in the simulation do not operate the call centre. In reality, the GP assistants and triage assistants man the call centre and the number of available phone lines is determined by the number of assistants that are in the call centre at that moment. This process is complicated to model, therefore, for now, we keep this simplification. We assume that three GP assistants are always available in the call centre, making it a process with three parallel servers. These GP assistants are invisible in the model. This simplification has some consequences for the reliability of the model outcomes. Not only are the waiting times for a telephonic triage influenced, also the waiting times for the other tasks that are performed by GP assistants and triage assistants are effected, since the modeled assistants do not need to divide their attention between the call centre and the waiting area. This indirectly also influences the occupancy of the GPs, because the assistants have time to take over some of the GP's tasks, such as consultations for less urgent patients. A more realistic modeling of the call centre is needed in the future to create more reliable model outcomes.

Another error we discovered by looking at the animations, is the fact that treatment at the ED sometimes starts while review tasks for that patient are still in progress. This is because, before starting treatment, the offline list is checked whether there are still review tasks for that patient on the list. But the review task is taken of the list as soon as it starts. This means that in the current simulation model, treatment can start as soon as every review task is started (instead of finished). Since most review tasks only take 2 minutes, this doesn't cause many problems. However the review of laboratory tests can take 30 or 60 minutes. In the simulation model, this causes situations in which lab review is started, treatment is started immediately thereafter and the treatment is finished before the review of the lab tests is finished. Therefore, it is important for future use of the model that this error is resolved.

At this moment, the offline review tasks also cause two other problems. First, we see many reviews performed by an ED nurse, even though this is not officially allowed. This is caused by the fact that, before every task is started, it is checked which staff member is required. To do this, the program checks a table for what the required type of staff member is for the next task the patient is waiting for. However, since offline tasks can be performed parallel to other tasks, the next sequential task is always treatment. For the patients for whom treatment can be performed by an ED nurse, it is therefore possible to see the ED nurse also review the test results. The second error we come across, is the fact that the patients that are send to make an X-ray through the GP post do not seem to get there results reviewed. This causes distortion in the amount of waiting time.

From the analysis above, we can see that the current simulation is not yet a perfect translation of the conceptual model. When all remaining problems in the simulation model are solved, we are one step closer to a useful simulation model. However, to determine the reliability of the model, we also have to check to what extend the model resembles reality. In the next section we will make a rough start with this validation.

6.3 A first validation of the simulation model

According to Law (2007), there are six different classes of techniques for increasing the validity and credibility of the model:

1. Collect high-quality information and data on the system
2. Interact with the manager on a regular basis
3. Maintain a written assumptions document and perform a structured walk-through
4. Validate components of the model by using quantitative techniques
5. Validate the output of the overall simulation model
6. Animation

A thorough validation, takes time that we do not have in this study. Therefore in this section, we will only look at some of the steps mentioned above in validating the model. Later on in the total research project, a more extensive validation process needs to take place.

The first technique mentioned by Law, on collecting high quality information and data on the system, was partially applied. By organizing regular project meetings with the involved stakeholders we got first-hand information on how the system of the IEP works. Unfortunately the reliability of the data we got from the databases of the GP post and the ED was doubtful. From observing staff members of the IEP during their work, we saw that the way in which registrations were made is not consistent, especially with respect to the time of registration. Also, information is stored for each patient on, for example, their origin, but the categories used are sometimes confusing and can be interpreted in more than one way. On top of this, because the IEP has only been opened since April 2010, we only have one full year of data to base our assumptions on.

The second class of techniques involves regular interaction with managers. To do this, we organized monthly meetings with the involved stakeholders to increase credibility of the model. In each of these meetings we handed out documents with questions and assumptions about the IEP, on which all project members gave feedback. This lead to the final set of assumptions as defined in Chapter 4 and 5. This thesis can therefore be considered as the final written assumptions document as described in the third class of techniques from Law. Although many assumptions have already been discussed through the discussion documents, a structured walk through of the final assumption document has not taken place yet.

The fourth class of techniques focuses on the use of quantitative techniques to validate parts of the model. We chose one important part to validate, namely the distribution of patient arrivals for the IEP and external. We used data from one simulation run of 10 years. In order to validate the amounts per hour for the different days, per weekday and per week, we calculated for each time interval the mean number of patients using the same method we used to determine the input amounts from the historical data (Appendices B and C). We then compared the historical average to the simulated average for that time interval. As an extra and more important check, we calculated the standard deviation per time interval. The historical standard deviation was not part of the simulation input, since we use a Poisson process, so it is useful to see whether the distributions used in the model creates the right amount of deviation. One of the characteristics of the Poisson distribution is that intervals with a big mean, have a big standard deviation and an interval with a small mean has a small deviation. In the historical data however, we find intervals that do not match these characteristics, because they have a small mean with a big standard deviation or vice versa. We can see this effect when we compare the historic standard deviation per time interval with that of the model output. The results of this analysis showed that for some time intervals the deviation was too high, and for others too low. In order to reach more similarity to the reality, we tested some interventions in which the inputted arrival distributions were adapted. After each iteration, the new values for the mean and standard deviation per time interval were compared to the historic values. After several iterations we came to new, best fitting settings for the arrivals of patients. These new settings can be found in Appendix N. Under the new settings, there is still a difference between the historical mean and standard deviation, and the simulation results. This is caused by the fact that we use the Poisson distribution. However, the distribution of deviation over the hours does follow the historic distribution roughly. To illustrate this, Figure 14 shows the historic and simulation distribution of deviation on Saturday for the arrivals through the IEP. We did the same comparison for the distribution on weekdays and Sundays for the arrivals through the IEP and for the external arrivals at the ED. For all situations, the distribution of the simulated data after the iterations roughly follows that of the historic data. To create an even better match to reality for the simulation model, more research must be done on whether it is useful to use another distribution instead of the Poisson distribution.

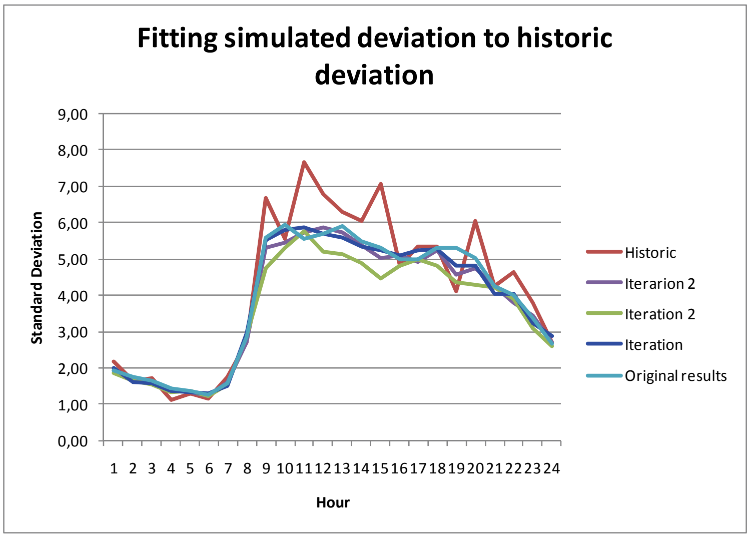

Figure 14: Deviation in the number of arriving patients per hour on Saturdays, historic data compared to simulated data

With the new arrival settings, a new simulation run of 4 years was done, simulating around 240.000 patients. From this run we performed a further analysis with respect to the overall outcomes of the simulation (class 5 according to Law). In Section 6.2, we described the analysis of the processing time, which were inputted into the simulation model as determined in the data analysis in Chapter 5. However, to check whether the model resemblances reality, we are now going to look at the data that we did not put into the model, but was generated as a resulting outcome: the waiting times per processing step. More specifically, for each processing step, we looked at the average, minimal and maximal waiting times, and time it takes for 95% of the patients to start the task. The results can be found in Appendix O.

Intuitively the results seem realistic, but we do see some odd results. For example, the waiting time for a consultation seem to be quite long. This is because in the final model, the waiting time for each step is registered, starting from the end of the previous step. For the consultation at the GP post, the previous step is either the telephonic triage or the triage at the GP post (for self-referrals). This means that for all patients that called the IEP first, the time they spend waiting at home is included in the registration. It would be interesting to also have data on the time those patients spend waiting for a consultation from the moment they enter the hospital for their appointment. Also we see that the waiting time for a triage at the GP post (for the self-referrals) always is minimal 5 minutes. This is an error in the simulation model, which causes every patient that enters the main hall, to wait in the entrance for 5 minutes before entering the waiting area. Since these issues are quiet small, there were directly resolved in the simulation model.

As a last validation step, we use the animation of the simulation model. In Section 6.2 we already used this technique to compare the simulation model with the conceptual model. Now we are going to do the same comparison for the simulation model and the real-world situation. In this model we see some things happening that do not seem realistic:

- A large amount of time, there are no GPs left at the GP post, because they are all at or traveling to patient homes for visits. In reality, a minimum of one GP stays behind to help the patients that come in for a consultation.
- The way in which the appointment times are modeled (see Section 5.9), causes odd situations in the simulation model. In the current model, the waiting times at home are deterministic and depend on

urgency. This means that a low urgent patient (category U4) always has to wait 3 hours before coming to the GP post for consultation, even when at the moment of calling no other patients are there. More research must be done on how to model the appointment times, to create a more realistic model.

- Because of the way in which personnel is prioritized (mostly according to costs), we see situations in which the GPs sit in the coffee room for a long time, while the triage assistant handles consultation from less urgent patients (categories U3 and U4). Even when a patient gets an appointment time for a GP consultation, most of the time the actual consultation is performed by a triage assistant or GP assistant. This does not seem realistically, so more research needs to be done on the subject of personnel assignment to tasks.
- Self-referrals need to be triaged when entering the IEP, preferably within 10 minutes after arrival. The triage assistant is specifically assigned to do these triages. However when the triage assistant is busy, the self-referred patients can be waiting a long time. In reality the triage would be performed by an available GP assistant. This is an error we made in authorization of tasks in the conceptual model. We have to change this authorization such that, in case the triage assistant is busy, but the GP assistant is available, the self referred patient can be triaged by the GP assistant.

From this analysis, we can conclude that the current model is a good start, but in order to get a more reliable model and thus more reliable results, some errors have to be fixed and some additional research might be required. For example the data analysis on the arrival distributions and on the route patients take through the IEP, can be extended as soon as the data from the second operational year is available. It can also be useful to organize a period of manual time registration, to get more reliable processing times to serve as input for the simulation model. Some improvement iterations are also necessary with respect to the modeling of appointment times and the assignment of personnel to different tasks. When the model is improved and assumed valid, it is useful to organize a validation session with involved stakeholders to demonstrate the simulation model and receive feedback. Only after the model is approved by the involved stakeholders and future users, it is ready to be used to evaluate organizational interventions.

Chapter 7 Discussion and conclusions

The goal of this study was to design the conceptual model of the IEP, to determine the input data for the simulation model and to verify and validate the final simulation model. To reach this goal, the following research questions needed to be answered:

- What is known about simulation models in general and about using simulation in healthcare?
- How are the processes structured at the Integrated Emergency Post?
- How can the processes at the Integrated Emergency Post be modeled?
- How usable is the final simulation model?

In Chapter 3, we described the theory of Law (2007) on designing a simulation model by following several steps. We also gave an overview of pitfalls and information on several related studies in healthcare. From this theoretical framework we understood the importance of establishing credibility, which we applied later on in the study when verifying and validating the simulation model. We also gave an overview of some of the simulation studies that were performed in the field of healthcare.

In Chapter 4, we described what processes take place at the IEP and how patients enter, move through and exit the IEP. In the same chapter, we also paid attention to how reality could be translated into the conceptual model. This conceptual model exists for a large part of assumptions that we made, based on the experience of staff members and members of the project team. The assumptions with respect to the relationships between included variables were tested by performing a data analysis with historical data in Chapter 5. Also, all assumptions were proposed to the members of the project team, who gave feedback until all assumptions seemed credible. To finish the conceptual model, the input data for the simulation model was determined from historical data.

The conceptual model was then directly translated into the computer simulation model and a description of the global structure was given in Chapter 6. To check to what extend this translation was correct, we used various verification techniques as described by Law (2007). Also, we used validation techniques to determine the model's resemblance to the real world situation. This verification and validation steps helped determining how reliable the model is to use.

When verifying and validating the simulation model, we came across a few points that still need improvement. There were some errors in the translation from conceptual model to the simulation model, mainly with respect to the offline reviewing tasks. Also the current way of modeling the call centre, by assuming a continuous crew of three GP assistants, causes unreliable results regarding the waiting times for tasks that can be performed by GP assistants. By performing several iterations we did manage to improve the resemblance between the actual arrival distributions and the simulated distributions. However, we must keep in mind that all data analysis is performed on data from only one year or less. To increase the reliability of the model, it is useful to extend this data analysis to a longer period, as soon as more data becomes available. On the aspect of processing times, which are currently based on estimates, it is advisable to collect some additional data too. Also, even though we had monthly meetings in which most of the assumptions were checked with involved stakeholders, the final simulation model is not yet entirely validated and approved by the stakeholders. This is necessary to increase the credibility of the model outcomes when testing interventions later on in the research project.

Overall, we can conclude that, with this model, a solid basis is laid down on which can be continued in the remainder of the research project. When all remaining errors have been resolved and the model is fully verified, validated and approved it can be used to test organizational interventions and analyze the results.

Chapter 8 Future Work

In the conclusion of this thesis, we determined that there are still some improvements that need to be made to the model. In this section we will elaborate on the research that still needs to be done in the direct future and the remainder of this research project.

The first thing that needs to be done, is correcting the errors in the model that we found when verifying and validating the model (Chapter 6.2 and 6.3). This means that more research must be done on how to model the way in which appointments for the GP post are planned. Also, the call centre has to be remodeled, such that the fact that the number of available phones depends on the number of GP assistants present in the call centre is taken into account, as well as the aspect that the call centre can not be left unattended.

Also, it is advisable to extend the data analysis to get more reliable input data. For the time dependent variables, this means using data from a period longer than one year. For the processing times, more reliable data needs to be collected. This can be done by improving the current registration methods, or by organizing a sample period in which all processing times are measured manually and compare this sample to the estimates as given in this thesis.

When the model improvements are finished, the stakeholders must be included in a more extensive validation process to establish higher model credibility. Ways to do this, are for example by organizing a structured model walkthrough in which the model is demonstrated and all underlying assumptions are presented. The stakeholders can also be subjected to a Turing test, in which they have to choose from two sets of data which values are the historical data and which values are the model outcomes.

As part of the overall research project we distinguish the following steps:

- Performing a stakeholders analysis on the preferred interventions to test with the model.
- Determine the important performance indicators on which the interventions can be compared.
- Test interventions by performing experiments with the simulation model.
- Analyze the possibilities to implement the interventions with positive testing results.
- Implement organizational interventions and monitor the effects at the IEP.
- Compare the results of real world intervention with the results from the intervention test with the simulation model.
- Investigate whether the simulation model can be used in other situations similar to the IEP Almelo.
- Analyze the overall effect of implementing the IEP with respect to the situation before the extensive collaboration through the IEP between GP post and ED.

After completing this research project, hopefully the gained knowledge can be used and applied to healthcare situations similar to that of the Integrated Emergency Post in Almelo.

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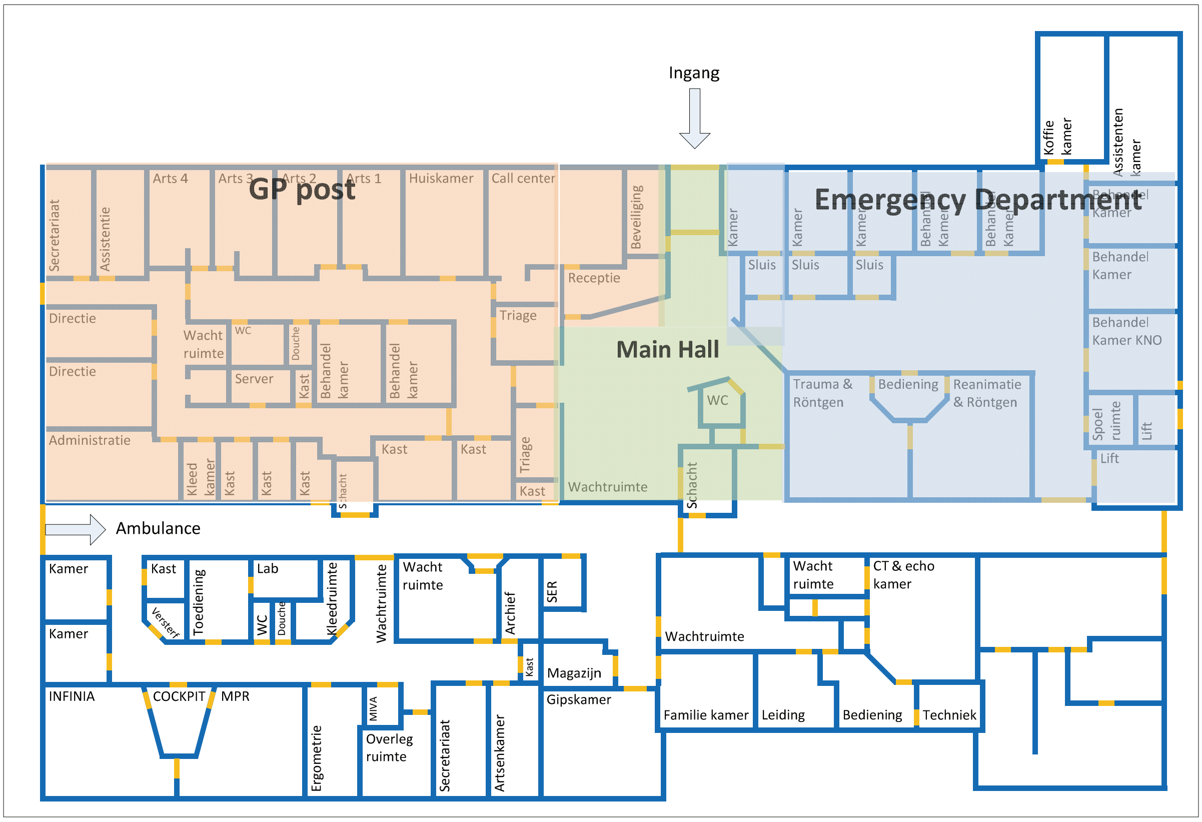
Appendices

Appendix A: Map of the Integrated Emergency Post



Appendix B - O

The content of these appendices is confidential.