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MASTERARBEIT

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Simulating the Patient Flow in an Emergency Department: A Case Study of the Emergency Outpatient Clinic for Internal Medicine in Vienna General Hospital

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List of Abbreviations

AB	agent-based
CI	confidence interval
CRF	case report form
DES	discrete event simulation
ECG	electrocardiogram
ED	emergency department
e.g.	for example
EMS	emergency medical service
ENT	ear, nose and throat
ESI	emergency severity index
FCFS	first come first served
ICU	intensive care unit
KPI	key performance indicator
KS-test	Kolmogorov-Smirnov-test
LOS	length of stay
SD	system dynamics
OR	operation research
UK	United Kingdom
WT	waiting time

1 Introduction

Playing the role of a 'gate-keeper', an emergency department (ED) determines whether a patient is admitted to a hospital's inpatient ward or not. Due to the high costs of inpatient care and the preference of most patients to avoid admission to a hospital, outpatient care is the favoured choice whenever possible [1].

Since the number of patients visiting EDs and outpatient wards increases steadily, overcrowded waiting halls in hospitals are a widespread problem. Besides the risk of poor medical outcome, this often leads to long waiting times for patients and results in dissatisfaction for patients as well as for medical staff [2]. The reasons for overcrowded waiting halls and long waiting times in EDs are diverse. Therefore hospital managers have to gain a better understanding regarding patient flow and resource utilization in their facilities. This can help identifying potential bottlenecks in order to reduce the amount of time a patient spends in an ED.

There are several techniques that can be utilized to evaluate ED performance. Using discrete event simulation (DES) coherences of different input factors in an ED can be evaluated. In addition the effects of changing resource levels or the general process flow can be tested without affecting general ED operations. The possibility of applying a 'what-if' analysis is one advantage of the application of simulation in health care, as endangering the well-being of patients by experimenting with real systems can be avoided.

The aim of this master thesis is to build a DES model that illustrates the patient flow in the Emergency Department of Vienna General Hospital (chair: Univ.-Prof. Dr. Anton N. Laggner). Thereby the model focuses on patients who visit the ED due to internal medical problems and are not admitted to hospital but treated at the outpatient clinic and discharged right away. These patients are treated within a medical treatment room of the ED's outpatient clinic, where also patients with other health problems (e.g. neurological or dermatological problems) are treated by ED physicians. In order to underline that in the created model only patients with internal medical problems are considered, the term 'emergency outpatient clinic for internal medicine' will be used in this master thesis. It shall be kept in mind that in reality there is no separate department for internal medicine at the ED of Vienna General Hospital and the term ‘emergency outpatient clinic for internal medicine’ is only defined for this master thesis.

The created model should identify potential bottlenecks within the process flow and a possible overutilization of resources that may lead to unnecessarily long waiting times for patients. Thereby the focus of research lies in patients’ throughput time and ED efficiency. Validating the model, the current state of the ED performance is simulated and the model’s outcome is compared to empirically observed data. A detailed analysis of the simulation outcome should provide insight in current ED performance and evaluate ED efficiency. In addition by applying a ‘what-if’ analysis it is observed how changing input factors, especially an increase of patients arriving at the ED, would affect patients’ throughput time and ED efficiency. The effects of adaptations to the general process flow at the ED as well as changes in clinical pathways and the number of available resources on ED performance and thus the model outcome is evaluated as well.

This master thesis is structured as follows:
Section 2 will give an overview of the applications of simulation in health care, focusing on simulation in EDs and outpatient clinics. Furthermore reasons for overcrowded waiting halls and long waiting times for patients are discussed. Section 3 describes the ED of Vienna General Hospital and the current process flow in this facility. In Section 4 the created DES model is explained in detail. After presenting the used input data, input and output data analysis are discussed. Thereafter an explanation of model implementation is given. In Section 5 model validation, as well as computational experiments, summarize the main findings of the simulation study. By applying a peak hour analysis and a bottleneck analysis it is observed how ED performance changes when the number of arriving patients increases significantly. Based on the results of the bottleneck analysis the ‘what-if’ analysis in Section 6 gives an overview of the effects on model outcome in case the process flow is modified. In addition changes in clinical pathways are tested and experiments with different resource levels are performed.

2 Applications of Simulation in Health Care

Simulation nowadays is a widely used technique and among other fields of application, can be utilized to describe processes in health care systems. Depending on the issue that should be depicted, different types of simulation can be used. Discrete event simulation (DES) is one available tool. Regarding health care specific simulation models DES can be utilized to explain patient flow, to examine resource utilization and to investigate relationships among different variables, e.g. arrival and service rates [3].

In this section an overview of the applications of simulation in health care is given. At the beginning the concept of simulation and the setup of a DES model are explained in a theoretic way. Thereafter the role of simulation in EDs and outpatient clinics is discussed.

2.1 Simulation Modelling

The aim of simulation modelling is to create a simplified representation of a complex system in order to gain better understanding of a system's behaviour and to understand certain behavioural aspects. Simplifications have to be made as an exact imitation of the real world would be very costly and laboratory. A simulation model can be used to evaluate system performance under ordinary and unusual circumstances, predict the performance of a not yet existing system or to rate and to compare multiple designs in a physical, analytical, mathematical or computer based model. Physical models imitate physical objects, whereas analytical models are sets of equations and relations among mathematical variables. Computer based models, like the model created in this master thesis, are program descriptions of the real world and can be seen as a type of mathematical model as well [4].

The main difference between analytical and computer based mathematical simulation models is, that in case of analytical mathematical models a single analytical solution is found. If the system that shall be depicted is too complex it will not be possible to find a single analytical solution. In this case, a computer based simulation is a good alternative, exercising the model numerically [5].

Computer based simulation was chosen to create a simplified model of the emergency outpatient clinic for internal medicine of Vienna General Hospital because of the complexity and uncertainty occurring in an ED.

2.2 Advantages and Disadvantages of Simulation

Due to the complexity of most real-world systems, it is often not possible to build a mathematical model, which provides an adequate analytical evaluation. Thus simulation is the only possibility to investigate [5].

Compared to other techniques simulation has several advantages. One benefit of simulation is the possibility of testing new adaptations to an existing system without actually changing the system. Experiments with not yet existing systems are possible as well. Moreover simulation can be used to gain better understanding of how a system works, how variables interact and how they affect a system's outcome. Bottleneck analysis may discover problems in the general process flow and mismatching resource levels. Furthermore 'what-if' questions can be answered and serve as a fundament for potential changes in the system [6].

A 'what-if' analysis is often used to evaluate the effect of systematic changes of independent variables on dependent variables. Different scenarios can be built and thus a hypothetical world can be tested and evaluated. Compared to a sensitivity analysis, the aim of a 'what-if' analysis is not solely to test how sensitive the output of a system is to small changes in input variables. Instead different scenarios should be built and analysed [7]. The possibility of applying a 'what-if' analysis is one big advantage of simulation. In health care, experimenting with existing systems can be very difficult and endanger the well-being of patients. With the use of a 'what-if' analysis, building new systems and testing different scenarios of existing systems is possible without any risks.

In addition simulation tools have a cost advantage compared to experiments with existing systems. High flexibility is offered as well, as once a model is built, it can easily be adapted by further assumptions. It is also possible to consider variability and uncertainty of input factors and the system's environment. This is very important, as in some industries e.g. the health care sector the demand can never be predicted for sure and thus will always be uncertain. Furthermore easy comprehension is provided due to the graphical interface of simulation software [8].

Nevertheless there are several disadvantages and drawbacks concerning simulation.

Building a model requires specific knowledge of the system's behaviour. Thus there are high requirements to the skills of model constructors. In addition the data that is used in the simulation model has to be gathered carefully, as savings in collecting and analysing the input data may affect the simulation outcome and might bias the results. The simulation outcome may be hard to interpret and has to be validated in order to make sure that the results are based on the system's interrelationships and not on random circumstances [6].

In addition simulation may be a very time consuming approach, especially when data has to be gathered first. The personal requirements and the purchase of simulation software may be costly as well, although compared to experiments with real systems there is still a cost advantage. All in all it has to be considered that a simulation is a simplified reproduction of reality and assumptions and restrictions have to be made, as including all potential variables and influences occurring in the real system is not possible. Therefore, there is no guarantee that the model outcome is a certain and perfect prediction of how a real system would behave [9].

Hence simulation is a very strong tool, as long as it is used in an appropriate and scientific way. Inadequate applications, on the contrary, will not lead to a convincing outcome.

Due to the variety of simulation approaches, a model constructor is obliged to characterise the dimensions and characteristics of a system in order to determine the approach that fits the system's properties. The next subsection summarizes the main dimensions of simulation and gives an overview of the most common simulation approaches.

2.3 The Dimensions of Simulation

Depending on the characteristics of a system, simulation models can be classified along three different dimensions. Therefore a simulation model is either

- static or dynamic,
- deterministic or stochastic,
- continuous or discrete.

Static models represent models at a certain point in time, whereas dynamic models evolve over time. Deterministic models are models without any probabilistic component. Stochastic models, on the contrary, are based on random input factors. Continuous models change instantaneously, discrete models only change at certain points in time, whenever an event occurs [5].

Considering the variety of the dimensions of simulation it was assumed that a dynamic, stochastic and discrete model would represent the characteristics of the system being studied in an adequate way. In the created model of the process flow in the emergency outpatient clinic for internal medicine the number of patients arriving at the ED e.g. is not constant throughout time and therefore can be described as a dynamic component. These fluctuations in arriving patients as well as the time needed to treat these patients cannot be predicted for sure, and are stochastic components in the system. In addition it is assumed that the state of the system only changes at discrete points in time e.g. whenever a new patient arrives at the ED. Thus, DES was chosen to model the patient flow in the emergency outpatient clinic for internal medicine.

Besides DES, system dynamic (SD) and agent-based (AB) modelling are the most common simulation approaches. Although the model created in this master thesis is a DES model, SD and AB modelling are now briefly discussed for the sake of completeness.

With the aid of SD, cause-and-effect relationships can be modelled. Using feedback loops and stock and flow diagrams, single events and entities are observed on an aggregate level. Interacting variables and direct casual links can be modelled.

AB modelling, on the contrary, experiments with models consisting of individual agents who interact within a conceptual environment. Agents representing single individual social actors, e.g. human beings, companies or countries, act in a predefined way within their environment. Those agents interact with each other; they can communicate by delivering massages and learn from their actions [10].

SD is mostly used to model continuous systems, whereas AB and DES both process on a discrete, event driven time horizon. In SD and DES models, system behaviour is predefined on a global level. In AB systems the individual behaviour of an agent is defined by the model constructor. Due to interactions within the environment, the system behaviour emerges [11].

Focusing on the characteristics of the presented simulation approaches, DES seems to be a good approach for modelling the system of interest. SD would not be appropriate due to the continuous time horizon. AB would be suitable for modelling the process flow for individual patients, but not for simulating the patient flow on a general level.

Since the created model is a DES model, the main idea of this approach will be described in more detail in the following section.

2.4 Discrete Event Simulation

DES is a technique for modelling systems that evolve over time. These systems are characterised by state variables which change at separate points in time, so-called events. An event can occur in many different ways, but its main feature is that it leads to a transition from one state of the system to another. Internally a simulation clock keeps track of all events that occur and the changes in state variables that are associated with these events [5].

The state of a DES model can always be represented completely by state variables. In the system being studied entities (patients and patient charts) as well as resources (treatment rooms, doctors, and administration clerks) are involved. In order to give a complete description of the system at a certain point in time all these elements have to be considered. The state variable of resources, such as doctor and administration clerk, can either be idle or busy. Treatment rooms can be available or not available. An event could e.g. be the arrival of a new patient, who requires treatment by a doctor. Due to the requested treatment the state of a doctor changes from idle to busy. Whenever the treatment is finished, the state changes back to idle.

There are various examples of discrete-event systems and an ED can be modelled using DES as well. In order to provide an overview of practical examples of DES in health care the next section summarizes some recent research developments.

2.5 Literature Review

Discrete event simulation is widely used for modelling health care systems. Especially since 2004 the number of publications focusing on simulation in hospitals increased markedly [12]. Literature reviews from the 1970's [13] show that simulation in health care has been performed for more than 30 years and the number of publications and literature reviews increases steadily.

A review from 2003 reveals that the majority of simulation models approach only discrete parts of hospitals, e.g. emergency rooms, outpatient clinics or operating theatres, as simulating a whole hospital is very complex [14]. The main aim of these studies is to support decision making and operational planning in health care [12]. In another review, covering mainly the same studies as presented in [14], it is stated that this lack of simulation studies dealing with whole hospitals results from the complexity of the systems and the large data requirements for modelling. In addition, monetary and time resource requirements may also lead to less research in this field [3].

The main focuses of recent simulation studies are reducing waiting times in outpatient clinics, staff demand in accident and emergency departments and utilization of hospital beds [12].

As the model presented in this master thesis refers to an emergency outpatient clinic, a brief literature review of studies dealing with EDs and outpatient clinics shall now be given.

2.5.1 Examples of Simulation in Emergency Departments

The main focus of research dealing with simulation in EDs lies on the analysis of waiting times and resource utilization. Short time horizons and processes that are easily observable may be crucial reasons for the high activity in this field of research and thus lead to a variety of suchlike simulation studies [12].

Samaha et al. [15] discovered that long waiting times in EDs can result from the process itself and not compulsorily from lacking resources. Komashie et al. [16] on the contrary, demonstrated that long waiting times in an ED may indeed depend on lacking resources, e.g. the number of nurses and doctors. In this case waiting times could be reduced significantly by adding resources to a specific ward. Brenner et al. [17] aimed to minimize length of stay, improve efficiency, and reduce overcrowding by analysing the patient flow in an ED in the UK. Using simulation a bottleneck in diagnosis testing was identified and patients' throughput time, waiting times, and length of stay could be reduced significantly by increasing the number of nurses and CTs.

Simulation studies, like those outlined above, are only few examples for ED specific simulation models and reflect one of the main problems concerning simulation in health care addressed in recent literature reviews [12]. One point of criticism is that most simulation models are case studies for specific facilities and are therefore rarely reused. Although there are doubts concerning the validity of reusing such models, it seems that the individuality of simulation models leads to high resource requirements and more general and more easily reusable models would be preferable.

There are different reasons for not reusing simulation models [18]. On the one hand, financial reasons may lead to a model constructor's refusal to share his or her work, as the willingness to pay for a model does not meet the constructor's expectations. On the other hand simulation software today is easy to use and thus it may be simpler and cheaper to build a new model instead of adopting an existing one to a new system [12].

Nevertheless besides the large diversity of facility based work, there are already attempts for general simulation models. A generic model explaining patient flow and interactions in EDs has been conducted by Sinreich et al. [1]. Simplifying the model in an extent that makes it easy to use and understand, the model presented in [1] represents ED processes on a universal level. Conducting a generic, reusable and transferable model was also intended in the UK [19]. This model was delivered to 10 National Health Services in the UK and actually implemented by three of them. The main finding in this study was that generic models are more successful when the dependencies on specific data collection are limited.

2.5.2 Examples of Simulation in Outpatient Clinics

Due to similarities between EDs and outpatient clinics it is not surprising that outpatient clinics are common settings for simulation studies as well. Thereby scheduling and capacity planning are frequently addressed. Furthermore, waiting times on the micro level (the time between a patient's arrival at the outpatient clinic and treatment by a physician) are of certain interest as well [12].

Inappropriate scheduling schemes often lead to long waiting times in outpatient clinics. After comparing appointment schedules in an ear, nose and throat (ENT) outpatient department in the UK, for example, waiting times could be reduced significantly by improving appointment management [20]. Different appointment and doctor schedules have also been evaluated in an outpatient clinic for internal medicine in Nagoya University Hospital. By determining optimal schedules, waiting times could be reduced significantly without adding further resources [21]. Focusing on the length of stay in a mammographic outpatient clinic in Brazil, an optimal appointment schedule was found. In addition capacity planning showed underutilization of resources, whereas an increase of patients by two thirds would still be manageable without changing the resource level [22].

Concerning simulation studies of outpatient clinics again the main research is done in simulating specific departments, but generic simulation studies are still available. CLINSIM, for example, is a generic model, constructed by the OR Division of the UK Department of Health and used in 20 clinics in the UK. Focusing on patients' waiting times the influence of operating policy on the time patients spend in outpatient clinics was observed [23].

The model presented in this master thesis is a case study, similar to the majority of DES models in hospitals. The main focus of research lies on patients' throughput time and ED efficiency.

In the next section the setting of the simulation model, the emergency department of Vienna General Hospital, and the current operations in the ED are explained in detail.

3 Current Operations in the Emergency Department

This section gives an overview of the emergency department of Vienna General Hospital and current operations in the emergency outpatient clinic for internal medicine. At first the structure of the ED is explained in detail, thereafter the patient flow in the emergency outpatient clinic for internal medicine is illustrated.

3.1 The Emergency Department of Vienna General Hospital

The necessity of an ED in Vienna General Hospital was already evident in the 1970s. Finally opened in 1991 at the ED medical aid is delivered twenty-four-seven and nearly 90.000 patients are treated each year, whereof 80.000 are only seen at the outpatient wards [24].

In 2011, 31% of all patients who arrived at the ED suffered from internal medical problems. The maximum number of patients who were treated at the ED due to internal medical problems per day was observed in February 2011 where 124 patients received treatment by an ED physician [25].

Figure 1 gives a simplified overview of the layout of the ED of Vienna General Hospital. The ED can be divided into three subunits: the emergency outpatient clinic, the emergency unit, and the observation ward which are explained subsequently. Furthermore an emergency laboratory is located in the centre of the ED.

In general, a patient enters the ED via the entrance and walks to the triage in the right corner of the waiting hall, where an ED nurse gets a first impression of the patient's physical condition. As soon as triage is finished the patient has to register at the front desk. While the patient has to wait for his or her examination by a physician he or she will stay in the waiting hall. A patient will only be seen at the observation ward or the emergency unit in case he or she is admitted to hospital. In any other case treatment will be performed in one of the treatment rooms of the emergency outpatient clinic. Waiting times for patients are possible before the triage, the administration at the front desk and the treatment within the treatment rooms. These waiting times, patients' throughput time, respectively the time patients need to go through all the processes mentioned above, as well as the utilization of resources in the ED are analysed. The resulting numbers are used to compare the ED performance of the current system and 'what-if' scenarios and evaluate the effects of changing input variables.

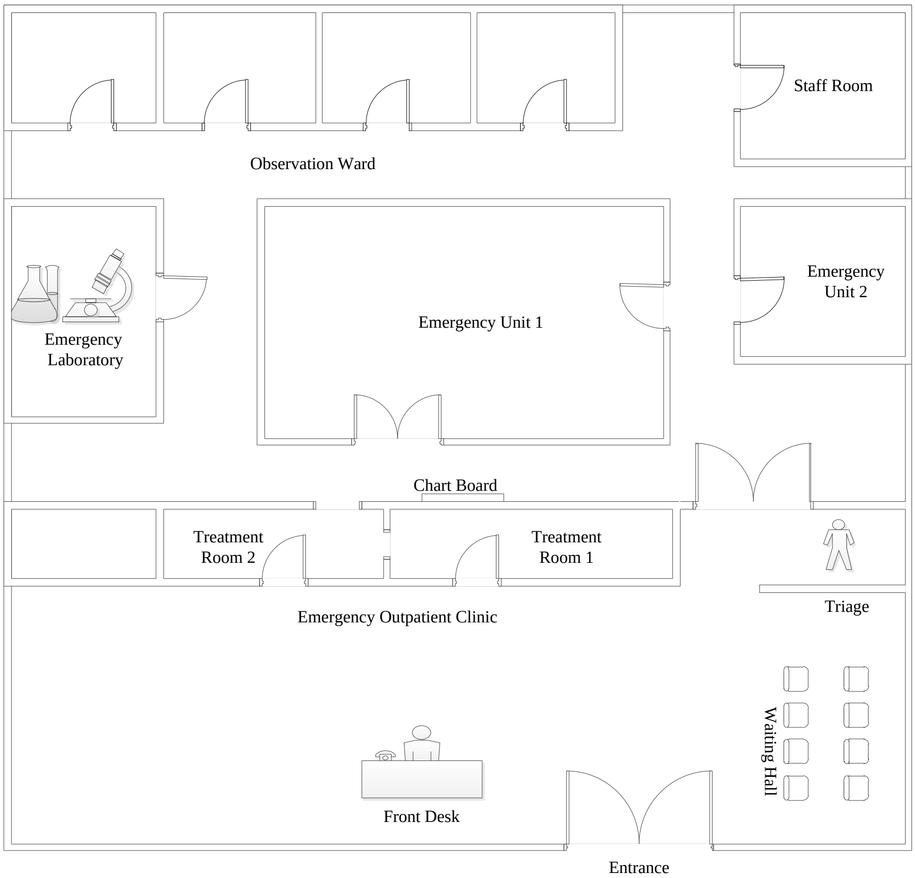

Figure 1 Simplified layout of the ED
(Source: own depiction)

For a more detailed description of the patient flow in the ED it is referred to Section 3.2, the analysis of ED performance will be outlined in Section 5. In advance the composition of the ED will be explained in brief in the next subsections.

3.1.1 Emergency Outpatient Clinic

The emergency outpatient clinic consists of 11 rooms for various medical speciality departments (dermatology, internal medicine, neurology, ENT, ophthalmology, gynaecology, orthopaedics, urology, surgery, and oral surgery). In the emergency outpatient clinic, patients for all speciality departments (except traumatology, psychiatry, paediatrics and neonatology), who have subject feeling or objective criteria of an emergency, are seen outside the normal operating hours of the general outpatient clinics of Vienna General Hospital (Monday to Friday, 08:00 to 15:00). During the regular opening hours of the other outpatient clinics, walk-in patients[1] are treated at the emergency outpatient clinic.

[1] **Walk-in patient** (noun): *a patient who arrives without an appointment.*
(Source: http://dictionary.reference.com/browse/walk-in)

This thesis focuses solely on the emergency outpatient clinic and on patients who arrive there due to internal medical problems. For the field of internal medicine two examination rooms (denoted as treatment room 1 and 2 in Figure 1) are reserved. Within these treatment rooms treatments are performed by ED physicians. Besides recording a medical history, patients are examined physically, ECGs can be written and drugs can be delivered. Furthermore physicians may take blood samples from the patients and discuss the results of diagnostic testing. The utilization of the two treatment rooms for internal medicine and the attending doctors are the main points of interest concerning ED efficiency. Therefore the focus of this master thesis lies on the processes performed within these two treatment rooms. These two treatment rooms for the field of internal medicine will be called ‘emergency outpatient clinic for internal medicine’ in this master thesis to underline the focus of the study. Nevertheless it should be kept in mind that in reality a suchlike separate department does not exist.

For the sake of completeness the purpose of the emergency unit, the observation ward, the emergency laboratory and how they are connected to the emergency outpatient clinic are briefly discussed as well.

3.1.2 Emergency Unit

The emergency unit consists of two examination rooms (denoted as emergency unit 1 and 2 in Figure 1) which allow simultaneous treatment of four respectively three intensive care patients. All beds are monitored centrally and supplied with oxygen, pressured air and vacuum exhausts. Patients under very serious health conditions are transferred directly to the emergency unit and are not treated at the outpatient clinic. After a diagnostic workup and an initial stabilisation a patient can be transferred either to an intensive care unit (ICU) or a regular ward of Vienna General Hospital or to another hospital. Otherwise the patient will be discharged directly.

3.1.3 Observation Ward

In the observation ward four rooms are available, whereof three rooms are equipped with three beds and one is a single bed room. The observation ward is mostly used to observe patients for 12 to 24 hours. In case of an emergency it can also be used as an ICU. Furthermore patients who arrive at the emergency outpatient clinic during the night and have to be admitted to hospital stay in this facility until they can be transferred to another unit of Vienna General Hospital or be discharged.

3.1.4 Emergency Laboratory

In addition the ED is equipped with an emergency laboratory, where blood gas analysis, oxymetry, lactate and electrolyte determination, as well as various rapid diagnostic tests can be performed. Using a pneumatic post system, the emergency laboratory is connected with the central laboratory as well as the blood bank of the Vienna General Hospital [24].

3.2 Patient Flow in the Emergency Outpatient Clinic for Internal Medicine

This master thesis focuses on the processes in the emergency outpatient clinic for internal medicine. In order to gain better understanding of the processes in the ED the following section describes the general patient flow in more detail.

The ED of Vienna General Hospital is located on level 6 D, next to the EMS[2] entrance [24]. Patients who are treated at the emergency outpatient clinic either arrive on their own – entering the building through one of the several entrances and following the signposting to level 6 D – or they arrive by ambulance and are escorted by paramedics. A yellow line on the floor at the entrance door to the ED signalizes this unit's separation from the rest of the hospital.

Having crossed this yellow line the patient is situated in the ED's waiting hall and is summoned by signposting to move to the waiting hall's right corner. There an ED nurse (triage nurse) surveys first vital parameters. According to the disorders described subjectively by the patient and those observed objectively by the triage nurse a cardinal symptom[3] is assigned to the patient. The triage nurse also suggests the medical specialty department by which the patient shall be seen.

Furthermore the triage nurse rates the patient's acuity using the emergency severity index (ESI) [26]. ESI is a tool for ED triage that considers the patients acuity as well as the intensity of resources needed to treat the patient. It is based on a five-level scale where 1 indicates the highest and 5 the lowest level of urgency and resource intensity.

[2] **EMS:** emergency medicine services

[3] **cardinal symptom** (noun): *the primary or major symptom of diagnostic importance*.
(Source http://www.medilexicon.com/medicaldictionary.php?t=87430)

In general this triage system is based on two main questions:

(1) When should this patient be seen?

(2) What does this patient need?

In case ESI 1 is assigned to a patient, treatment should be performed immediately. Patients of the category ESI 2 can wait up to ten minutes. Patients with an ESI level from 3 to 5 can wait longer until being treated by a physician [27].

Regarding the question of what the respective patient needs, ESI 1 is assigned to a patient in case immediate live-saving interventions are required. For patients who are either in a high risk situation, confused, lethargic or disoriented or suffer from severe pain, the ESI level 2 is designated. In all other cases the number of resources that are required to treat the patient is considered in the assignment process of the ESI level. If there are no resources needed to treat the patient ESI 5 is assigned. In case one resource is required ESI 4 and if more resources are needed ESI 3 is chosen. In the latter case danger vital signs may also lead to a consideration of choosing the ESI level 2. In order to get a better understanding of the assignment process of ESI levels to a patient a flow chart illustrating this process is depicted in Figure 2.

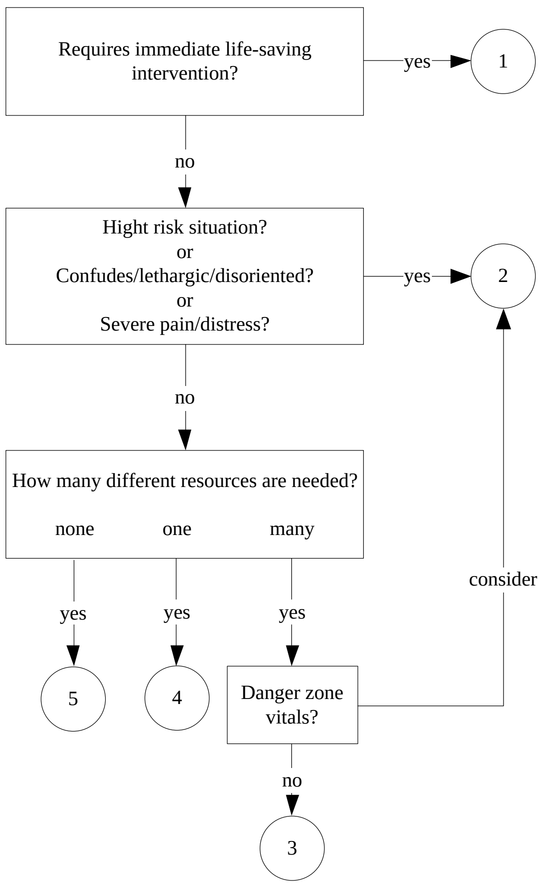

Figure 2: ESI triage algorithm
(Source: own depiction after: ESI Triage Research Team, 2004.)

Patients who are assigned with ESI 1 will not be seen at the emergency outpatient clinic. They are transferred to the emergency unit immediately. Patients of all other ESI categories move to the front desk as soon as triage is performed. There an administration clerk records the required personal and insurance data. These data, as well as the data gathered at the initial review by the triage nurse, are collected in a patient chart. Once administration is finished the patient is invited to take a seat in the waiting hall and wait there until a doctor calls him or her to one of the treatment rooms.

In the meantime the patient chart remains at the front desk and an administration clerk carries it to a chart board that is located in the corridor behind the treatment rooms. ED physicians get informed about the arrival of a new patient by observing this chart board. Whenever a new patient chart was added to the chart board, an ED physician takes the chart and examines the corresponding patient as soon as all resources for performing treatment are available.

Referring to the prior assigned ESI level the chart board offers separate shelves for each ESI level. Due to the higher acuity and priority of ESI 2 patients, the recommended maximum waiting time for these patients is ten minutes. Therefore an ED physician treats ESI 2 patients prior to all other ESI levels. Concerning ESI 3 to ESI 5 patients, an ED physician prefers the patient who arrived first. Having picked a new patient chart, the physician moves to one of the two available treatment rooms. Patients are notified that they will be seen next by a physician via loudspeaker announcements. The physician will mention the name of the patient who is next in line as well as the number of the treatment room, where the examination will be performed.

The treatment a patient receives after entering the treatment room depends on his or her cardinal symptom and his or her medical history. Further information referring to treatment that is delivered within the treatment rooms can be found in Section 4.3.2.

If a blood sample or an X-ray has to be taken, the patient needs to stay at the ED until all results are available. In this case he or she moves back to the waiting hall and waits for a second call. The corresponding patient chart is brought back to the chart board and inserted to a separate shelf indicating that the patient has already been seen by a physician and the attending physician is waiting for test results.

If no further examinations are needed, the patient can be discharged right away. If the patient's physical condition requires inpatient care, he or she is admitted to the emergency unit, the observation ward or a regular unit of the hospital. Whenever a patient is admitted or discharged, the corresponding patient chart gets filed.

A patient has to wait in the waiting hall until all requested results are available. When all results are available the physician will ask the patient to move to one of the treatment rooms again. The physician then decides whether the patient is admitted, discharged or further examinations have to be made.

All in all the patient flow in the emergency outpatient clinic for internal medicine in Vienna General Hospital comprises several processes. The key processes are triage, administration and at least one treatment by a physician. Before each key process the crucial question is if all resources needed to perform this process step are available. In case the resources are available, the patient is treated immediately. Otherwise the patient has to wait. Thus waiting times for a patient are possible before each of the key processes. In addition a patient may leave the system after each of the key processes. In case ESI 1 is assigned to the patient he or she is transferred to the emergency unit immediately and leaves the system right after the triage. If the patient is seen by another specialty department than internal medicine he or she leaves the system after the administration at the front desk. As soon as the first examination by a physician is finished the patient is either discharged or admitted to hospital and thus leaves the system or he or she has to wait for test results and walks to the waiting hall again. In the latter case the patient is seen by a physician repeatedly until all test results are available and the patient is discharged or admitted to hospital.

Figure 3 visualises the general patient flow in the emergency outpatient clinic for internal medicine and indicates at which point a patient can leave the system.

As waiting times are possible at different points in the system being studied a better understanding of how delays in the patient flow emerge shall be provided. Therefore the next subsection outlines some reasons for overcrowded waiting halls and long patient waits.

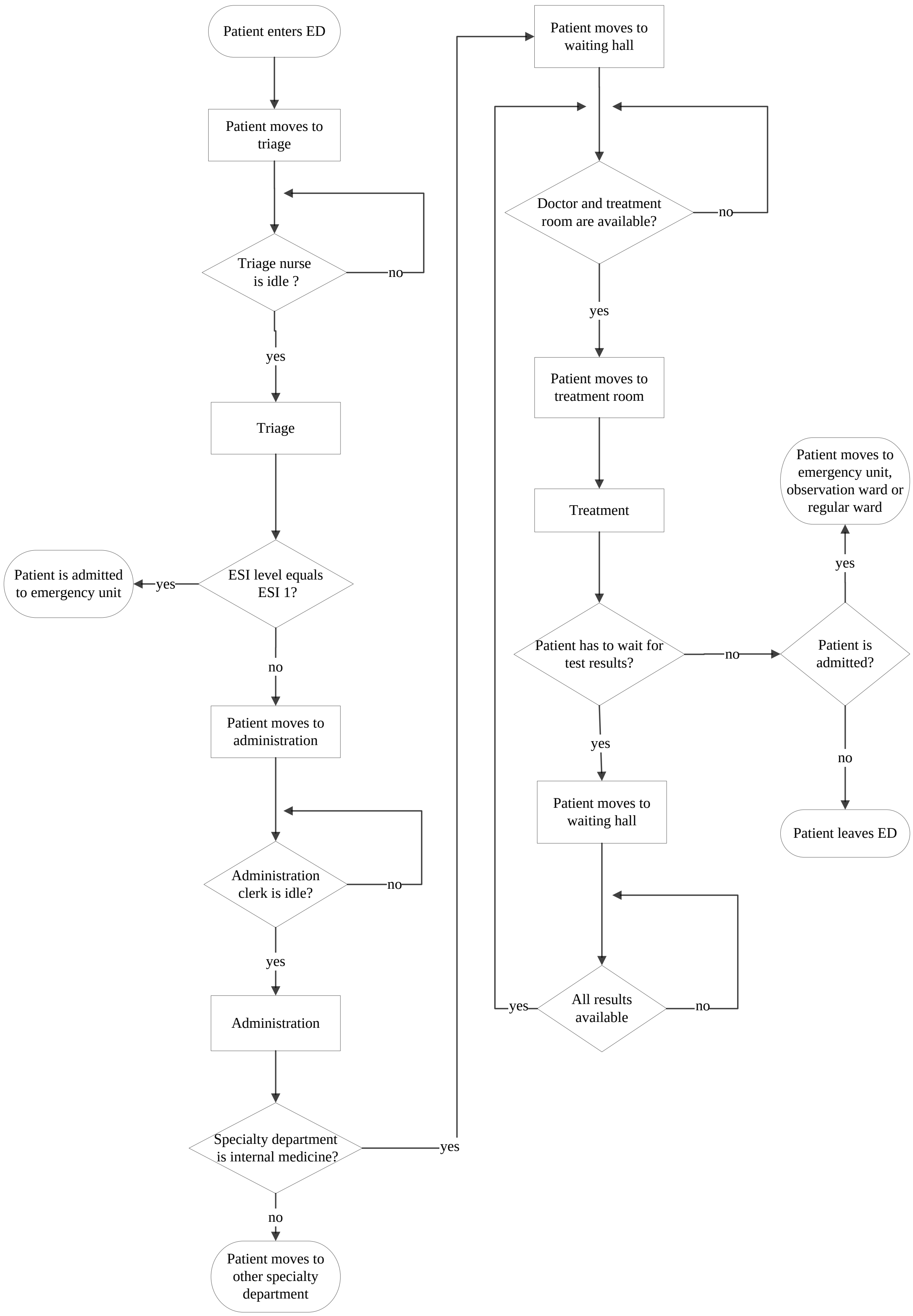

Figure 3: Patient flow in the ED
(Source: own depiction)

3.3 Reasons for Overcrowded Waiting Halls

In general EDs are often associated with long waiting times and overcrowded waiting halls [2].

Although there is no explicit definition for ED overcrowding, the term refers to a situation of a high demand of patients in treatment areas, exceeding ED capacities and the necessity to provide medical treatment in ED hallways [28, 29]. The reasons leading to overcrowded EDs are complex and multifarious and thus are now explained in brief.

EDs can not only be seen as ‘gate-keepers’ to hospitals, sometimes they are also considered as substitutes to primary care providers, like the general practitioner or the family doctor. Guttmann et al. [30] estimated that about 90% of all patients visiting an ED are discharged after receiving care, whereas only 10% of all patients are in such bad condition that they have to be admitted to hospital. This complies with the number of admissions and ambulant patients in the ED of Vienna General Hospital from 1995 to 2008 [24].

Furthermore the number of patients who request medical advice from ED physicians increased during the last decades. In Vienna General Hospital 54.528 patients have been seen in the ED in 1995. By 2008 this number had increased by more than 60% [24].

Although a large proportion of ED visits are non-urgent [31], the treatment of patients is getting more and more complex and time consuming. Due to advancing technology EDs nowadays are able to perform far more tests. On the one hand this leads to an improvement in the quality of care but on the other hand it extends the time a patient stays in an ED. Thus delays in services provided by radiology or laboratory are very time consuming. A shortage of staff (e.g. doctors and nurses) or restricted resources (e.g. hospital beds) may also lead to long waiting times in EDs [2].

Due to the variety of potential influences on a patient’s length of stay (LOS) in an ED, it is not possible to give a general explanation for overcrowded waiting halls, keeping in mind that not even a precise definition for this term exists. Instead using simulation the patient flow in a specific system can be modelled and by varying input factors and process sequences different scenarios and their consequences can be tested in advance.

The aim of this master thesis is not to make a statement whether the Vienna General Hospital is affected by the problem of ED overcrowding. Instead the patient flow in the emergency outpatient clinic for internal medicine of Vienna General Hospital shall be modelled in order to get a better idea of why patients have to wait and before which treatment steps waiting times occur. The proportion of waiting time and time required for treatment shall be analysed and bottlenecks in the patient flow shall be identified. In order to evaluate where patients have to wait longer, a separated analysis of waiting times before different steps in the patient flow is made.

A detailed description of how the patient flow in the emergency outpatient clinic for internal medicine of Vienna General Hospital was modelled is given in the following section.

4 The Simulation Model

The following section describes the constructed simulation model and all its components in detail. Thus an overview of how the real system explained in Section 3 was rebuilt in the computer based simulation model is given. First the input data that has been used is presented followed by a short description of data collection as well as input and output data analysis. Simplifications made in the simulation model and dependencies between input variables are defined at the end of this section.

4.1 Input Data

As the patient flow in the emergency outpatient clinic for internal medicine of Vienna General Hospital is very complex and each patient receives several treatments depending on his or her physical complaints and condition, a variety of input data was used to simulate this system. Table 1 summarizes the used input data.

patient data	**duration of single treatment steps**	**resource units**
interarrival time at ED	triage and administration	number of doctors
age	get and read patient chart	number of administration clerks
gender	conducting a patient history	number of treatment rooms
cardinal symptom	physical examination	
ESI level	ECG	
type of movement	taking a blood sample	
	preparation and delivery of drugs	
	explanation of further investigations	
	filling out forms	
	other therapy	
	results of blood tests	
	get patient chart again	
	discussing results	

Table 1: Used input data

As shown in Table 1, the used input data can be divided into three main categories: patient data, duration of single treatment steps and resource units.

Patient data refers to demographic data (e.g. age and gender) of patients visiting the outpatient ward as well as information concerning their physical condition. The physical condition of patients is characterized by the type of movement (walking, sitting, or lying), the cardinal symptom – meaning the physical harm that induced the patient to visit the ED – and the ESI level. Potential influences of these input variables on patients' LOS have been analysed. Furthermore the time of patients' arrivals at the ED was used to compute interarrival times.

As there are several treatments a patient receives during his or her examination by a physician and every single procedure takes a certain amount of time, the according durations of the most common treatment steps have been utilized as well. These durations have been necessary in order to evaluate the time a patient actually receives treatment.

In addition specific resource units have been considered in the simulation model. The numbers of the resources (doctor, administration clerk, and treatment room) which are available to deliver treatment to patients have been used.

The category resource units is the only deterministic component concerning input variables in the simulation model. The number of available resources was assumed to be fixed in advance as in the real system staff schedule as well as the infrastructure at the ED allow less uncertainties concerning the number of available resources. Patient data and the duration of single treatment steps, on the contrary, cannot be predicted for sure and are probabilistic input variables. Thus the collected input data was used to estimate distribution functions for these variables.

The next subsection describes how the used input data was collected. Thereafter the input data analysis for probabilistic input variables will be explained in detail.

4.2 Data Collection

Two different sources of data have been utilized to generate input data (as summarized in Table 1) for running the simulation model. For specifying patients' interarrival times a data source was made available by staff members of the Department of Emergency Medicine of Vienna General Hospital. For all other input variables data was gathered in June 2012.

Interarrival times have been estimate based on the data set collected by staff members of the Department of Emergency Medicine. The data was collected between July 2008 and June 2009 and covers all days of the corresponding year. This data set was primarily collected for a former study and contains a survey sample size of N = 15610.

For specifying the distribution of the other input variables data was collected in June 2012 over a period of 12 days. Workdays and weekends were covered in the same proportion and all 24 hours of those 12 days were recorded. Data was collected by observing physicians in the treatment rooms of the outpatient clinic for internal medicine of Vienna General Hospital. Patients' age, gender, ESI level, type of movement, and cardinal symptom were noted on a predefined case report form (CRF). In addition start and end time of individual treatment steps were recorded. As observation only took place inside the treatment rooms of the outpatient clinic for internal medicine the times of triage and administration were taken from the patient chart. The triage nurse and the administration clerk always note the time of occurrence of the respective treatment by hand in the corresponding patient chart. At the end of the data collection, a survey sample size of N = 345 was available. This data set was then utilized to estimate the underlying probability distributions of the attributes mentioned before.

In order to create a simulation model that is based on stochastic input variables random number generators, which generate variables based on a distribution function, are required. The next section outlines how the used input distribution functions were estimated.

4.3 Input Data Analysis

Based on the empirically observed data, probabilistic distributions were estimated. The observed data itself could also be used as input variables, but this would only allow a reproduction of situations which have happened historically [5]. Thus the empirically observed data was solely used for model validation. The simulation model itself works with the estimated distribution functions.

Empirical distribution functions of the collected data were estimated. With the aid of standard techniques of statistical interference, empirical distributions were compared with theoretical distributions. Kolmogorov-Smirnov-tests were used to determine the goodness of fit of the selected distributions. It was decided to define theoretical distribution functions, through which also values outside the observed range can be generated. In addition these distributions smooth out certain irregularities of empirical distributions [5].

The results of the input data analysis for the categories patient data and duration of single treatment steps are outlined in the following subsections.

4.3.1 Patient Data

This subsection specifies the input data analysis of patient related variables. Before describing the analysis of demographic characteristics, cardinal symptom and ESI level, it is explained how interarrival times were estimated.

Interarrival times

Patients' interarrival times have been computed based on the data set collected by staff members of the Department of Emergency Medicine mentioned in the previous section. This choice was made as this data set contains a larger data base of N = 15610 compared to the data gathered in June 2012.

In a first step it was analysed if the number of patients arriving at the ED is constant over the whole day or if there are time-dependent fluctuations. Therefore data was plotted. Figure 4 illustrates the fluctuations of patients arriving at the outpatient clinic during a 24-hour period. On the x-axis 24 one hour intervals are depicted, the y-axis shows the percentage of patients arriving per time interval. It can be seen from Figure 4 that especially in the morning hours fewer patients arrive at the emergency outpatient clinic for internal medicine. In the afternoon on the contrary a peak in patients' arrivals can be observed.

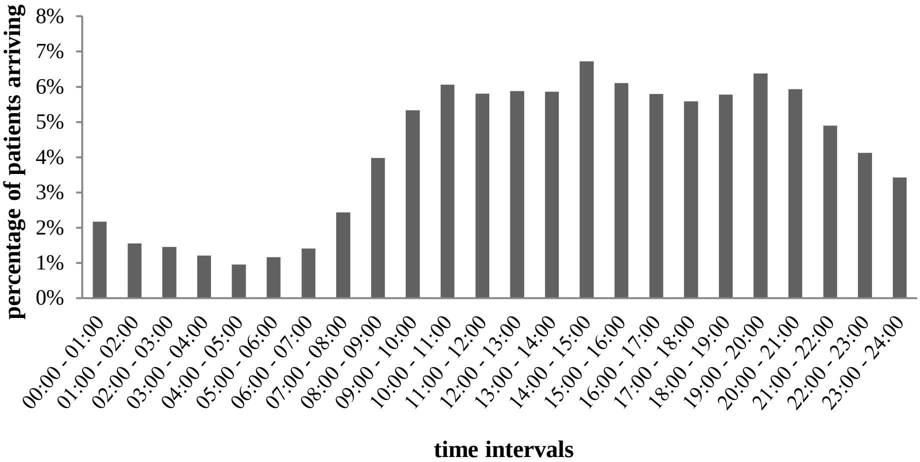

Figure 4: Fluctuation in number of patients arriving on all days of the week

Due to the fluctuations in the average number of patients arriving at the ED per time interval, interarrival times have been computed time-dependent. Six four hour intervals have been chosen to estimate the corresponding distribution functions. According to the recorded time of arrival, the data sets have been analysed separately in the following time intervals: 00:00 to 04:00, 04:00 to 08:00, 08:00 to 12:00, 12:00 to 16:00, 16:00 to 20:00, and 20:00 to 24:00.

In addition to a time-dependent evaluation of interarrival times it was checked whether interarrival times vary according to the day of the week. Using the Mann-Whitney-U-tests for unknown variances [32], it was tested whether there are significant differences between mean interarrival times of patients on a certain day of the week. Every combination of days has been compared and U-tests showed a significant difference in mean interarrival times for Thursdays with a level of significance of $\alpha = 1\%$.

We decided to restrict the simulation model to a typical day of the week. Thursday was chosen for further examinations and thus a survey sample size of N = 2200 was available for defining distribution functions. As illustrated in Figure 5 there are strong similarities to the results summarized in Figure 4 concerning the fluctuations in patients' arrival times. There are less patients arriving before noon, compared to a peak of arrivals in the afternoon. The prior defined six hour intervals have thus been retained and data was evaluated separately for each time interval.

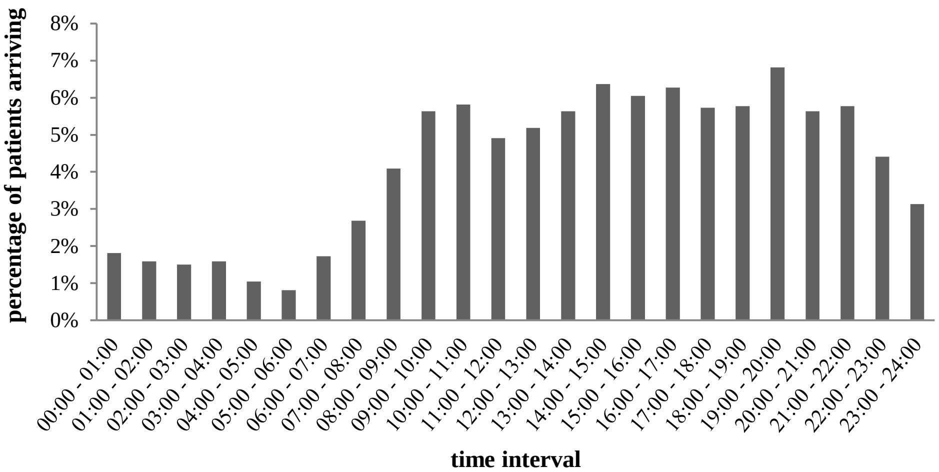

Figure 5: Fluctuation in number of patients arriving on Thursdays

Histograms of the calculated interarrival times have been plotted for each time interval in order to visualize the underlying distribution functions. Based on the shape of the histograms it was assumed that the interarrival times are exponentially distributed. Thus least square estimators for exponential distributions have been defined. A parameter λ, expressing the mean interarrival time, was estimated for each time interval. Mean interarrival times are stated in the column 'interarrival time' in Table 2. In addition the average number of patients arriving within the corresponding time interval is given in Table 2.

After defining empirical distribution functions for exponentially distributed data for each time interval, KS-tests were performed in order to evaluate goodness of fit of the estimated distribution functions. The results of KS-tests are summarized in Table 2 as well. The column 'KS-test' states the test statistic for this hypothesis test. The null hypothesis (H_0 = data is exponentially distributed) is rejected with a level of significance of α = 1% in case the test statistic is bigger than the critical value of 1.308. Since none of the test statistics exceeded this critical value, the null hypothesis has not been rejected and goodness of fit could be verified for each time interval. Therefore based on the calculated λ time-dependent interarrival times have been generated randomly in the simulation model.

time interval	interarrival time (in minutes)	patients per minute (λ)	patients per hour (λ)	KS - test
00:00 – 04:00	60.0672	0.0166	0.9989	1.2632
04:00 – 08:00	75.7244	0.0132	0.7923	1.3051
08:00 – 12:00	30.4487	0.0328	1.9705	1.2061
12:00 – 16:00	24.0475	0.0416	2.4951	0.7255
16:00 – 20:00	21.9613	0.0455	2.7321	1.0047
20:00 – 24:00	25.3819	0.0394	2.3639	0.7682

Table 2: Interarrival times on Thursdays

Summarizing it can be stated, that patients' interarrival times are exponentially distributed. The time-dependent evaluation of interarrival times showed a peak of patients' arrivals between 16:00 and 20:00. Approximately 2.7 patients arrive per hour within this time interval. Therefore analysing the outcome of the model, there will be an evaluation of ED performance of a 24-hour period as well as a separate analysis during peak hours.

Demographic Characteristics, Cardinal Symptoms, ESI Level and Clinical Pathways

In addition to patients' interarrival times, demographic patient data was analysed.

Patients visiting the ED are on average 44 years old, whereas there is no significant difference in the average number of arriving women and men.

Referring to the distribution of ESI levels, only 1% – 3% of all patients who visit an ED are ESI 1 patients. Since ESI 1 patients are not treated at the emergency outpatient clinic for internal medicine, they are not considered in this study. ESI 2 level patients represent 20% – 30% of all patients. The proportion of ESI 2 patients, visiting the ED during the time of data collection was in accordance with the general proportion stated in literature [27]. 29.97% of all recorded patients were categorized with ESI 2. The majority of patients were triaged with ESI 3 (58.41%), 10.40% with ESI 4 and only 1.22% with ESI 5.

Based on former experience the most common cardinal symptoms for internal medical problems in the emergency outpatient clinic of Vienna General Hospital have been defined in advance. Those included abdominal pain (25.22%), thoracic pain (20.58%), dyspnoea (9.56%), headache (1.74%), hypertension (2.90%), palpitation (2.03%), general malaise (5.51%) as well as other complaints (32.46%), whereas the quoted percentage shows the observed proportion.

It was assumed that the cardinal symptom of a patient is the main influence on the required treatment steps. This assumption was based on the data gathered in June 2012 where the same treatment steps have been delivered in response to all cardinal symptoms, but in coherence with the main cardinal symptoms they appeared with different probabilities. Hence clinical pathways have been defined for each cardinal symptom. While for every patient visiting the ED a patient history was conducted, only 93.10% of all patients complaining about abdominal pain received a physical examination. Patients complaining about headache were examined in this specific way in only 66.67% of all cases. The proportion of patients receiving any form of medication was the highest for patients with dyspnoea (90.91%), whereas patients with thoracic pain received this form of treatment only in 28.17% of all reported cases. A detailed overview containing all probabilities of occurrence in accordance with the main cardinal symptoms can be found in Table 3.

It shall be mentioned, that the values stated in Table 3 only refer to the probability that a certain treatment step is delivered within one of the treatment rooms for internal medicine of the emergency outpatient clinic and does not include treatments that are delivered by ED nurses at the triage or in the waiting hall. Thus the percentage of patients complaining about thoracic pain receiving e.g. an ECG is lower than in reality, as in case of suspected heart attacks ECGs are written right at the triage.

	abdominal pain	thoracic pain	dyspnoea	headache	hypertension	palpitation	general malaise	other complaints
conducting a patient history	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
physical examination	93.10%	78.87%	69.70%	66.67%	40.00%	85.71%	57.89%	54.46%
ECG	6.90%	67.61%	33.33%	16.67%	70.00%	57.14%	36.84%	17.86%
taking a blood sample	81.61%	78.87%	84.85%	66.67%	60.00%	71.43%	84.21%	81.25%
preparation and delivery of drugs	66.67%	28.17%	90.91%	83.33%	50.00%	14.29%	36.84%	47.32%
explanation of further investigations	83.91%	81.69%	57.58%	50.00%	60.00%	57.14%	68.42%	63.39%
filling out forms	87.36%	76.06%	87.88%	100.00%	70.00%	71.43%	89.47%	77.68%
other therapy	13.79%	8.45%	18.18%	50.00%	10.00%	28.57%	26.32%	10.71%
discussing results	75.86%	76.06%	75.76%	83.33%	80.00%	57.14%	47.37%	46.43%

Table 3: Probability of occurrence for certain treatment steps

The probabilities stated in the last row of Table 3 represent the share of patients who have to wait for certain test results e.g. of blood tests and thus are seen by a physician a second time. 75% of patients with abdominal pain e.g. have to wait for a discussion of test results, 25% leave the ED after one consultation with an ED physician.

The clinical pathways depicted in Table 3 are only based on the estimated probability of occurrence referring to the main cardinal symptoms. Their purpose is primarily defined for the created simulation model and further investigations would be necessary to make valid statements and suggestions for clinical pathways in the emergency outpatient clinic for internal medicine in Vienna General Hospital. As the clinical pathways consist of various treatment steps, in the next subsection the duration of the corresponding treatment steps are estimated.

4.3.2 Duration of Single Treatment Steps

Based on the recorded starting- and endpoints of single treatment steps during data collection in June 2012, the duration of all individual procedures was calculated.

Relationships between the time a patient arrives at the ED, the duration of single treatment steps delivered by medical staff, as well as patients' demographic and physical characteristics were assumed. Thus correlation coefficients between age, gender, cardinal symptom, ESI level, type of movement, arrival time and all durations of single treatment steps were calculated, in order to evaluate if any of the patient characteristics might affect the time needed to perform a certain treatment step.

Concerning patient characteristics, the strongest correlation was observed between the variables patient's age and type of movement. It can be assumed that the probability that a patient arrives in a lying position is higher, the older the corresponding patient is. This positive influence is shown by a correlation coefficient of $r = 0.3168$.

Referring to the relationship between patient characteristics and the time needed to perform certain treatment steps the strongest relationship was observed between the time of arrival and the delivery of other treatments. A correlation coefficient of $r = -0.2499$ led to the assumption that delivering other therapy takes longer in case the patient arrives very early in the morning, maybe due to restricted availability of resources in the early morning hours.

For all other input combinations, correlation coefficients were closer to zero. Since none of these correlation coefficients showed a significantly strong positive or negative relationship between the observed input variables, delay times for different treatments were analysed without further diversifications according to patients' characteristics.

Using descriptive statistics and graphical illustration in terms of histograms, the collected data was analysed and empirical and theoretical distribution functions were figured. Graphical illustration led to the assumption that all delay times are gamma distributed.

For gamma distribution a shape parameter α ($\alpha > 0$) and a scale parameter β ($\beta > 0$) were determined using least square estimators [4]. Goodness of fit was evaluated by comparing the empirical distributions to hypothetical gamma distributions using the Kolmogorov-Smirnov-test [5].

Table 4 shows the estimated parameters of the duration of single treatment steps. The test statistic for the hypothesis test is stated in the column 'KS-test'. The null hypothesis (H_0 = data is gamma distributed) is rejected with a level of significance of $\alpha = 1\%$ in case the test statistic is bigger than the critical value of 1.628.

	KS-test	Gamma(α,β)
1. triage and administration	0.8227	3.00 , 2.92
2. get and read patient chart	1.5997	1.20 , 0.64
3. conducting a patient history	1.1899	1.57 , 2.55
4. physical examination	1.0373	1.68 , 0.84
5. ECG	0.7113	5.79 , 0.60
6. taking a blood sample	0.6201	2.06 , 1.95
7. preparation and delivery of drugs	0.5721	1.72 , 1.77
8. explanation of further investigations	0.9056	1.25 , 0.75
9. filling out forms	1.1595	1.40 , 1.30
10. other therapy	0.9550	1.30 , 2.40
11. get patient chart again	1.0740	1.95 , 0.12
12. discussing results	1.0036	1.90 , 3.00

Table 4: Distributions of duration of single treatment steps

As none of the test statistics exceeded the critical value of 1.628, KS-test for gamma distributed data sets was verified for all treatment times. The estimated parameters α and β have thus been used for generating input data in the simulation model.

In addition to the duration of the treatment steps mentioned in Table 4 a delay in the performance of blood tests had to be considered. All blood tests, except blood gas analysis, are performed in the central laboratory of Vienna General Hospital. ED physicians take blood samples from patients and send these samples to the central laboratory using a pneumatic post system. As observing the time needed to perform a blood test in the central laboratory was not possible, the duration of this procedure was estimated by practitioners for internal emergency medicine. They estimated that it takes approximately 90 minutes until the results of a blood test are available.

In order to gain a better understanding of why and where the input variables discussed in this section were used and how the outcome of the model was measured, the following section focuses on the implementation of the simulation model.

4.4 Implementation of the Patient Flow

The created DES model was implemented using the simulation software *AnyLogic 6.6.0*. In order to model the patient flow in the emergency outpatient clinic for internal medicine a networked based modelling approach was chosen. This approach offers the possibility to include movement of entities and resources in a predefined network [33].

The layout of the simulation model is illustrated in Figure 1 on page 12. The resource units that were used in the simulation model are deterministic input variables and the number of available resources was fixed in advance. Therefore the number of treatment rooms is in line with the two treatment rooms depicted in Figure 1. In addition there is one administration clerk, who generally stays at the front desk, but can also move to the chart board behind the treatment rooms, in case he or she has to carry patient charts. The level of doctors was set to two. Doctors are normally situated in one of the two treatment rooms, but can also move to the chart board. All resource levels can easily be changed in *AnyLogic*. Therefore an analysis of the effect of different resource levels is possible.

Besides resources, entities are an important component in the simulation model. Entities are objects which take part at the process flow, access resources and store information [34]. These entities are generated randomly based on the interarrival times in Section 4.3.1 and represent the patients in the ED. Furthermore special attributes, like gender and age, as well as cardinal symptom, ESI level and type of movement are added to the entity as soon as it was generated. Those attributes are allocated in accordance with the predefined probability distributions as well. In addition every patient is assigned with a unique ID, in order to enable references to specific entities during the simulation process.

In reality triage and administration are performed on every single patient who arrives at the ED, no matter to which speciality department he or she is assigned. As the interarrival times of patients used in the simulation model refer only to those visiting the emergency outpatient clinic due to internal medical problems, utilization of triage nurse and administration clerk, as well as the waiting times before these processes would not be significant. Thus no valid analysis of the utilization of these resources and waiting times before these processes can be made. Nevertheless the performance of triage and administration requires a certain amount of time, whereas ignoring these process steps would bias the total time a patient spends in the system.

Therefore the two steps triage and administration are summarized in one treatment step in the simulation model. The time required to perform the triage, walk to the front desk and wait for administration is thus subsumed under the duration of the administration. As a result entering the network the patient walks to the front desk right away.

During the administration a patient chart is created. This step was added in the simulation model as two separate process flows take place starting from this point in time. The patient leaves the front desk and walks to the waiting hall whereas the patient chart stays at the front desk. The patient’s further flow is dependent on the flow of the corresponding patient chart.

The patient chart can be described as a second entity which contains all attributes of the entity patient. This can be guaranteed by copying all attributes stored in the entity patient to this new entity as soon as it is generated. Patient charts are brought to the chart board behind the treatment rooms by an administration clerk whenever he or she is idle. It is important to add this step in the process flow, as this time lack between a patient’s arrival at the ED and the time a doctor is informed about his or her arrival, also exists in reality. The time lack results from the dual task of the administration clerk of administrating new patients on the one hand and carrying the patient charts to the chart board behind the treatment rooms on the other hand. This dual task is implemented in the model by requests to the administration clerk from both the patient and the patient chart.

In reality the administration clerk will only leave the front desk to carry in the patient charts when he or she has sufficient time to do so or the amount of patient charts is high enough that he or she decides to intermit administration and bring in the patient charts. In the simulation model requests of patients waiting for administration have higher priority, whereas patient charts are only brought to the chart board when certain conditions are met. Whenever less than five patients are waiting for administration and at least one patient chart is at the front desk the administration clerk will leave the front desk and carry the patient charts in. The same will happen, whenever no patient is waiting for administration and at least one patient chart is at the front desk.

Doctors observe the chart board and will get notice about the arrival of a new patient whenever a new patient charts is added. In the simulation model this is implemented as follows: In the moment when the patient chart is added to the chart board, a request is sent to a doctor. In case a doctor is idle he or she will walk to the chart board and get the patient chart. If all doctors are busy the patient chart has to wait. As patients with an ESI level of 2 should wait no longer than ten minutes until they are seen by a doctor, the queue of patient charts waiting for a doctor is priority based. ESI 2 patients have a higher priority and a doctor will always take ESI 2 patient charts first. Patient charts of the category ESI 3 to 5 are treated according to the first come first served (FCFS) principle. This waiting line is the only priority based queue in the model, the remaining queues are handled according to FCFS.

When a doctor takes a new patient chart he or she will read the patient chart to get a first impression of the patient’s disorders and needs. The corresponding duration of reading the patient chart was implemented based on the distribution defined in Section 4.3.2. After reading the patient chart the doctor walks to one of the treatment rooms and occupies it. Then he or she calls the corresponding patient to come to the treatment room. In order to make sure that the right patient walks to the treatment room, the ID of the patient chart is compared with the IDs of all patients who are waiting. The entity which is attributed with the same ID will move to the doctor.

In reality the treatment a patient receives is dependent on his or her individual needs and thus cannot be generalized. In the simulation model it is assumed that the treatment only depends on the cardinal symptom stored in the entity. Entering the treatment room, the patient's cardinal symptom is checked. The treatment steps and the sequence of delivery are equal for all cardinal symptoms and refer to the treatment steps 3 to 10 in Table 4 (on page 29). Referring to the clinical pathways that have been defined as part of the input data analysis, the probability of occurrence of all therapies varies in accordance with the main cardinal symptoms. The clinical pathways are stored in a list that defines the sequence of treatment steps. In the simulation model this list is stored in the entities patient and patient chart and is completed step by step. In order to make sure that all treatment steps are delivered to the patient internally a counter determines which treatment step has to be executed next and the patient leaves the treatment room as soon as treatment is finished. When the patient leaves the treatment room the state variables of the resources treatment room and doctor change to idle again, so that the next patient in line can be called.

Figure 6 illustrates the process of a doctor delivering treatment in a treatment room and shows the sequence of therapies generating the clinical pathway for the first examination by a physician.

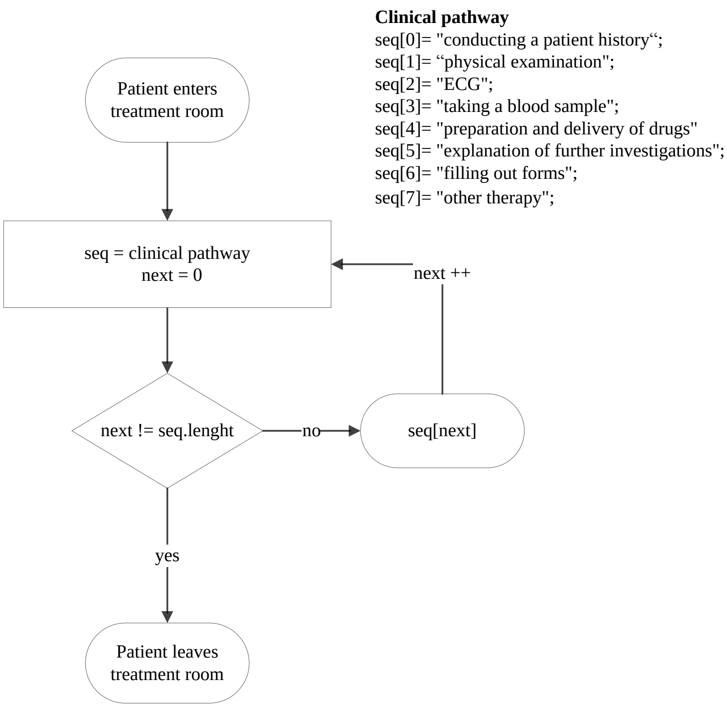

Figure 6: Clinical pathway for the first examination by a physician

In case a diagnostic treatment (e.g. blood tests) had to be performed, or any medication was given to the patient, a second examination by a doctor is required. The probability that a second treatment is necessary also depends on the cardinal symptom. Empirical observed probabilities that a second treatment is performed can be found in Table 3 (on page 28). The probabilities in accordance with the corresponding cardinal symptoms are stated in the row ‘discussing of results’. E.g. patients with abdominal pain are seen by a physician a second time in 75.86% of all cases.

The patient’s further flow is dependent on the probability that it is necessary to see the doctor a second time. Patients who are discharged right away as well as the corresponding patient chart leave the system. Those patients who have to wait for a second examination, respectively for the discussion of test results, walk back to the waiting hall and wait until all results of the performed examinations are available and the doctor has time to see the patient again. In the meantime the corresponding patient chart is brought back to the chart board.

When all required results are available and the doctor is idle he or she will get the patient chart once again and call for the corresponding patient. After discussing the results, the patient is discharged or admitted and leaves the system. The according patient chart is filed. In the simulation model the same exit from the system is provided for discharge and admission.

Once the entity left the system, it is deleted but the attributes that are stored in the entity are transferred to statistic collectors and stored there. Important information for evaluating the KPIs summarized in the next subsection can be gained from histograms that are plotted based on the statistical collectors. The throughput time of an entity is measured by subtracting the time an entity entered the system from the time of leaving. The result expresses an entity’s LOS. In addition waiting times before single treatment steps as well as the total waiting time are measured. These data are stored in statistical collectors, which calculate the average throughput time, respectively the average LOS as well as the average waiting times. By measuring the start and endpoint of treatment by a physician, information concerning the length of treatment is gathered as well. This information is used for model validation. At the beginning and at each possible end of the simulation model a counter is implemented in order to evaluate the average number of entities in the system. Patients in the waiting hall are observed in the same way.

The next section will give a more detailed explanation of the output analysis. Therefore the main points of interest concerning ED performance will be outlined.

4.5 Output Analysis

In order to analyse the model's output, a variety of Key Performance Indicators (KPIs) have been defined. Similar to other simulation studies in this field of research, patients' throughput time and ED efficiency are in the centre of attention. Patients' throughput time indicates the average length of stay (LOS) in the system, consisting of average waiting times, walking times and treatment times. ED efficiency refers to resource utilization [35].

Waiting times are evaluated in total and diversified according to specific processes in the patient flow. A diversified analysis is necessary in order to analyse where patients have to wait longer and where potential bottlenecks may occur.

Total waiting time consists of waiting time for the triage, for the administration at the front desk, for the first examination by a physician, and for discussing the results. As only patients visiting the emergency outpatient clinic for internal medicine are considered in the simulation study, waiting times for triage and administration will not be evaluated. In reality also patients from other specialty departments are seen at the triage and at the front desk, whereas the results of the simulation study would not be significant, due to the lower amount of patients that is considered in this model. Therefore the total waiting time includes only the waiting time for the first examination by a physician and the waiting time for discussing the results.

A patient's waiting time for the first examination by a physician is the time interval between the arrival at the waiting hall and the loudspeaker announcement that invites a patient to move to one of the treatment rooms. Waiting time for discussing results measures the time from the re-arrival at the waiting hall to the second announcement by a physician.

The average treatment time for the first examination by a physician is evaluated in total as well as depending on the main cardinal symptoms. A separate analysis depending on the cardinal symptom was chosen as, due to the different probabilities of delivery of certain treatment steps depending on the cardinal symptom, the average treatment times for all cardinal symptoms deviate from each other.

The average time needed for discussing results, on the contrary, is valid for all cardinal symptoms. The cardinal symptom only affects the probability of occurrence of this treatment step, but not the time needed to perform it.

Besides waiting and treatment times also the number of patients waiting for certain process steps is evaluated. In addition the average number of patients in the system and in the waiting hall, respectively the average number of patients waiting for treatment by a physician, is recorded. The average number of patients arriving at the ED is evaluated as well.

ED efficiency is measured by observing resource utilization, focusing on the utilization of doctors and treatment rooms. Attention should be paid to the fact that the simulation model is a simplification of reality and not all treatments that are performed by ED doctors are considered and depicted in the simulation model. Real resource utilization thus would be higher compared to the results of this study.

Table 5 summarizes the KPIs defined for the output analysis.

throughput time	**average number of patients**
average LOS average total waiting time average duration of the first examination by a physician average duration of discussing results	waiting for first examination by a physician waiting for discussing results in the system in the waiting hall arriving at the ED per day
diversified waiting times	**ED efficiency**
average waiting time for first examination by a physician average waiting time for discussing results	utilization of doctors utilization of treatment rooms

Table 5: Summary of KPIs

During the model implementation certain simplifications of the real system have been unavoidable. Thus the following section summarizes the main restrictions of the simulation model.

4.6 Simplifications and Limitations

Due to the complexity of the system certain simplifications had to be made during model implementation in *AnyLogic*.

Interarrival times have been estimated based on a data set from 2008/2009 as there was no access to more recent data which included the time of arrival of patients. Based on the available data in the simulation model 40 – 50 patients are treated at the emergency outpatient clinic due to internal medical problems each day. Staff members of the Department for Emergency Medicine stated that currently on weekdays about 70 patients are treated at the ED due to internal medical problems, whereas on weekends this number is still higher. This can be verified by a statistic summarizing the number of patients arriving at the ED each day in the year 2011. Referring to this data set per day on average 72 patients were treated at the ED due to internal medical problems [25].

Triage and administration are two independent processes in reality but due to the focus on processes inside the treatment rooms of the emergency outpatient clinic for internal medicine these two steps are combined in the simulation model. As a result no evaluation of a patient's waiting time before triage and administration can be made. At the triage and the front desk also patients from other speciality departments of the ED of Vienna General Hospital are seen. Thus statements concerning these waiting times and the utilization of triage nurse and administration clerk would not be significant. In reality utilization rates would be higher and waiting times longer, compared to the simulation model where only patients of the emergency outpatient clinic for internal medicine are considered.

Concerning clinical pathways only the probabilities of occurrence of single treatment steps are used to define which treatment will be delivered in accordance with the cardinal symptom. In reality other factors would influence the treatment that is delivered as well. Moreover not every possible treatment that may be delivered in an ED is considered in the simulation model. We limit the treatment steps to those summarized in Table 4 on page 29, but given appropriate data, the model could easily be extended to include additional steps. Furthermore the sequence of procedures in the simulation model is assumed to be fixed in advance, whereas in reality the sequence may vary depending on the physician's choice or exogenous influences.

Referring to resources used in the simulation model we consider all doctors to be homogeneous. Every doctor needs the same amount of time to deliver treatment, no matter what training, experience, gender or age he or she has. The assumption that the characteristics of a physician influence the length of treatment [36] is neglected in the simulation model.

Furthermore there is a focus on the utilization of doctors and additional staff e.g. nurses or medical students are not considered in this study. Hence it was assumed that there are no nurses or students in the treatment rooms and the doctor will perform every treatment step on his or her own. In reality this will not always be the case. Vienna General Hospital is a teaching hospital and students will support physicians from time to time during the examination of patients. As there is no fixed schedule when students assist in the ED, their existence will be neglected in the simulation model and it is assumed that doctors are alone in the treatment rooms.

The utilization of the resource doctor includes only the performance of the treatment steps summarized in Table 4 on page 29 (e.g. conducting a patient history, physical examination, etc.). However in real life doctors have additional duties, e.g. training medical students, documentation, etc. The time required for such additional tasks was not included in the simulation model and hence they are not reflected in the utilization rates. The utilization results solely from activities related to direct patient care. Recent studies showed that a physician spends approximately 20% to 30% of his or her time on direct patient care, the remaining time is spend on tasks which are indirectly related to patient care, e.g. documentation or consultation with medical staff [37, 38, 39].

In addition the number of treatment rooms is defined in advance and treatment can only be delivered in the treatment rooms.

Summarizing it shall be mentioned, that although certain assumptions and simplifications had to be made during model implementation the model is still an accurate reproduction of the real system. In the next section model verification and validation will prove that the assumptions and simplifications made above do not bias the results of the model. In addition the results of a simulation of the current state at the ED are outlined in detail.

5 Analysis of the Current State

The following section focuses on validating the implemented model. The current state of the emergency outpatient clinic for internal medicine was modelled and its operations simulated.

This section starts with a brief discussion of the chosen simulation design. Thereafter the results of the model validation and the current ED performance are presented. In the end of this section a peak hour analysis and a bottleneck analysis provide an overview of the effect on ED performance in case demand increases, e.g. during peak hours or in case of unexpected events.

5.1 Simulation Design

For simulating the current state at the emergency outpatient clinic for internal medicine a simulation runtime of 101 typical days was chosen.

In order to avoid biased output due to warm-up effects of an empty system the first day was considered a warm-up phase. At the beginning of the simulation run there are no entities in the system and all resources are idle. In reality, on the contrary, there may already be patients at the emergency outpatient clinic for internal medicine, either waiting for, or receiving certain treatments. By warming up the system it is attempted to reach a steady state of the system and avoid biased output data resulting from shorter waiting times during the warm-up phase [5].

Therefore data gathered on the first day of the simulation runtime has not been considered in the output analysis. The simulated outcome represents the average values of 100 days at the emergency outpatient clinic for internal medicine.

This simulation design was used for the analysis of the current state as well as for the 'what-if' scenarios.

5.2 Model Validation

To ensure an accurate implementation of the model and hence the credibility of the obtained results model validation was performed.

The process of deciding whether a model is an adequate reproduction of the system being studied can be divided into three steps: model verification, validation and credibility. The relationship between these three steps is illustrated in Figure 7. The rectangles represent the actual state of the system. The actions which are necessary to move to the next state are depicted below the horizontal arrows. Above the corresponding actions the applications of the concepts of verification, validation and credibility are shown [5].

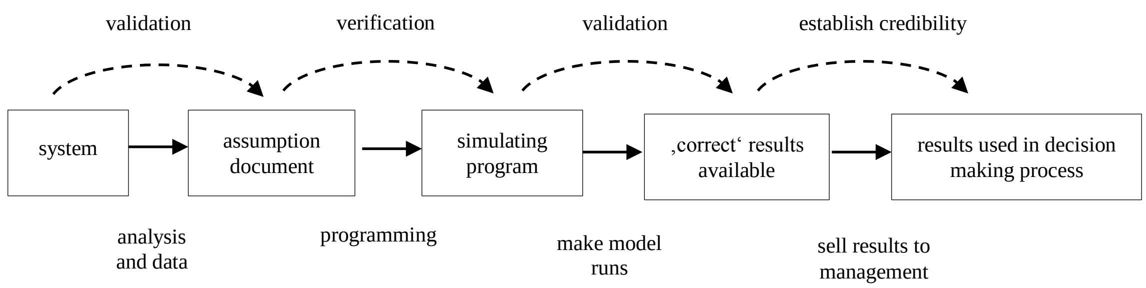

Figure 7: Relationships between validation, verification and credibility
(Source: own depiction after Law at al. 1992, p. 245)

There are many different approaches for testing the validity of a model [5] but nevertheless a model can never be validated completely. Determining the validity for a model’s whole domain of application areas would be too costly and time consuming, whereas validation is often restricted to the intended applications [40]. Therefore passing certain tests does increase the credibility of the results, but there is still no guarantee that the model is perfectly valid.

Referring to model validation, one can distinguish between conceptual and operational model validation. Conceptual model validation examines if the assumptions and theories for the model are reasonable. Operational model validation, on the contrary, checks the adequacy of the model output [41].

In order to prove the reasonability of the underlying assumptions of the created model, conceptual validity was checked during the time of data collection. By observing the general patient flow in the ED and by consulting practitioners of the Department of Emergency

Medicine adaptions to the prior defined theories were made until the conceptual model was an adequate reproduction of the real system.

After proving conceptual validity, the model was computerized step by step. For determining whether a conceptual model was implemented accurately, model verification can be used. Concerning computerized simulation models, verification requires a computer model that is free from programming errors. This can be achieved e.g. by debugging the program [42]. During the process of model implementation, the model was tested periodically in order to detect and fix programming errors. As *AnyLogic* is equipped with a JAVA compiler which cancels the simulation run and outputs an error message in case a programming error occurs, the correctness of the model's syntax was easily observable and the model thus verified.

As soon as the model was implemented and the input data was available, operational model validation could be performed by checking the accuracy of the model output. Therefore, statistical tests and graphical illustrations were performed. The numerical and graphical comparison between the simulated outcome and empirically observed data is outlined in the following subsections.

The last step in the process of deciding about the adequacy of a simulation model was to achieve model credibility. Therefore, the simulation model was demonstrated to physicians of Department of Emergency Medicine of Vienna General Hospital in January 2013. After presenting the simulation model and the model outcome to practitioners, they ensured that the assumptions made for the model are comprehensible and reasonable. In addition the output of the model seems to be an accurate reproduction of real waiting and treatment times.

All in all, the verification, the validation – which will be explained in detail in the following subsections – and the credibility model have been proven for the created simulation. Therefore the model can be used to evaluate current ED performance and to answer 'what-if' questions.

Before focusing on the results of a simulation of the current state at the ED, the next subsection describes the outcome of numerical operational model validation. Thereafter a graphical illustration of the simulated and empirically observed data is performed.

5.2.1 Numerical Model Validation

Statistical tests have been used in order to perform a numerical model validation. All simulated KPIs referring to patients' throughput time and waiting times – that have been defined in Section 4.5. – have been compared with the empirically observations. The Mann-Whitney-U-test for unknown variances was used in order to evaluate whether the simulated outcome deviates significantly from the empirical data.

In a first step the Mann-Whitney-U-test was utilized to test whether there are significant differences in the simulated and empirically observed mean service and waiting times. The null hypothesis for the Mann-Whitney-U-test (H_0 = there is no significant difference in mean values) is rejected with a level of significance of $\alpha = 1\%$ in case the test statistic is outside of the interval -2.576 and +2.576.

Table 6 gives an overview of the model validation for the corresponding treatment and waiting times, whereas all stated durations are measured in minutes. The column 'empirical' refers to the empirically observed mean waiting and treatment times. The average simulated values can be found in the column 'simulated'. The corresponding test statistics for the hypothesis test are stated in the last column of Table 6.

		empirical	**simulated**	**U-test**
throughput time	LOS	116.4051	119.1812	-0.0822
	total waiting time	74.8485	85.9062	-2.5197
	duration of the first examination	14.3162	14.2643	-2.0056
	duration of discussing results	6.1056	5.7258	-0.0088
diversified waiting times	waiting time for first examination	27.8893	27.3397	-1.6265
	waiting time for discussing results	104.7182	98.3784	-1.7135

Table 6: Key data for model validation

As all critical values stated in Table 6 lie within the 99% confidence interval, the null hypothesis of the Mann-Whitney-U-test is not rejected. Therefore, it can be assumed that there are no significant differences in mean treatment and waiting times for empirically observed and simulated values. The simulation model reproduces empirically observed output accurately and the operational model validation can thus be proven statistically.

In addition to the numerical approach of model validation a graphical approach was chosen for operational model validation. The results of graphical illustration are summarized in the following subsection.

5.2.2 Graphical Model Validation

Besides a numerical model validation simulated and empirically observed data was also compared graphically. Histograms have been plotted in order to visualize the distributions of the observed waiting and treatment times. This should illustrate at which points the simulated outcome differs from empirical observations.

The results of graphical model validation are depicted in Figures 8 – 16, whereas Figures 8 – 10 deal with the comparison of patient related input data and Figures 11 – 16 focus on treatment and waiting times. In all figures referring to graphical model validation simulated values are illustrated by darker histogram bars, while empirical observations are coloured in a lighter tone.

Figure 8 shows the distribution of patients' age. For analysing the distribution of this variable, age groups within a range of 20 years have been defined. These age groups are depicted on the x-axis of Figure 8. The percentage of observations per age group is shown on the y-axis.

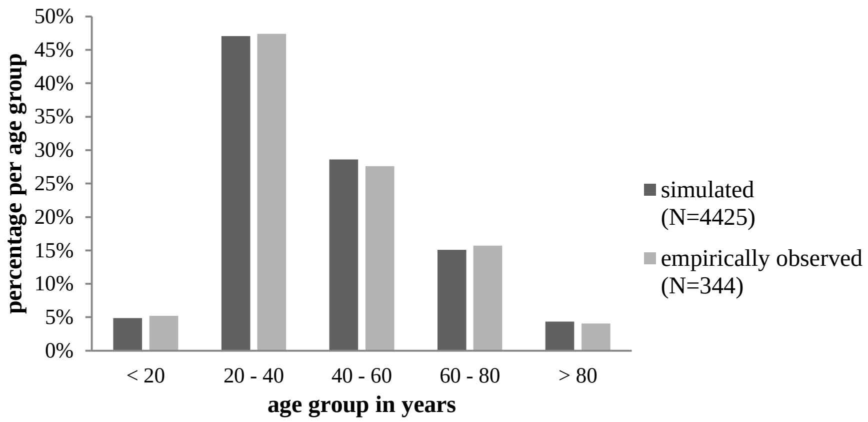

Figure 8: Comparison of patients' age

The majority of patients visiting the emergency outpatient clinic for internal medicine are between 20 and 40 years old. More than 50% of all patients visiting the ED are younger than 40 years. Only about 4% of all patients are over 80 years old. These shares are valid for simulated as well as empirically observed patients.

Figure 9 outlines the distribution of ESI levels. The four categories of ESI levels are depicted on the x-axis, while the percentage of observations per ESI level is shown on the y-axis. The majority of all patients visiting the ED are ESI 2 or 3 patients, only 12% of all simulated and empirically observed patients are triaged with a higher ESI level.

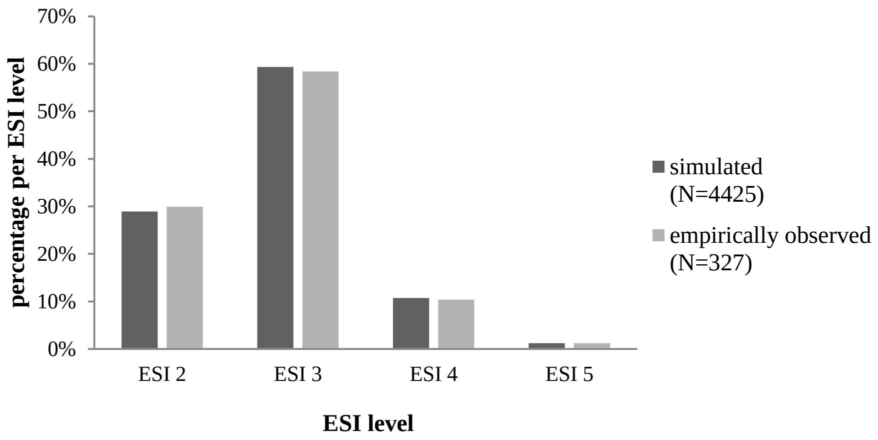

Figure 9: Comparison of patients' ESI level

The distribution of the most common cardinal symptoms is illustrated in Figure 10. Cardinal symptoms are depicted on the x-axis, the percentage share of each cardinal symptom is shown on the y-axis. Almost 50% of all patients visiting the emergency outpatient clinic for internal medicine complain either about abdominal or thoracic pain. The category of cardinal symptoms 'other complaints' occurs frequently as well. Approximately 32% of all simulated and empirically observed cardinal symptoms can be subsumed under this category.

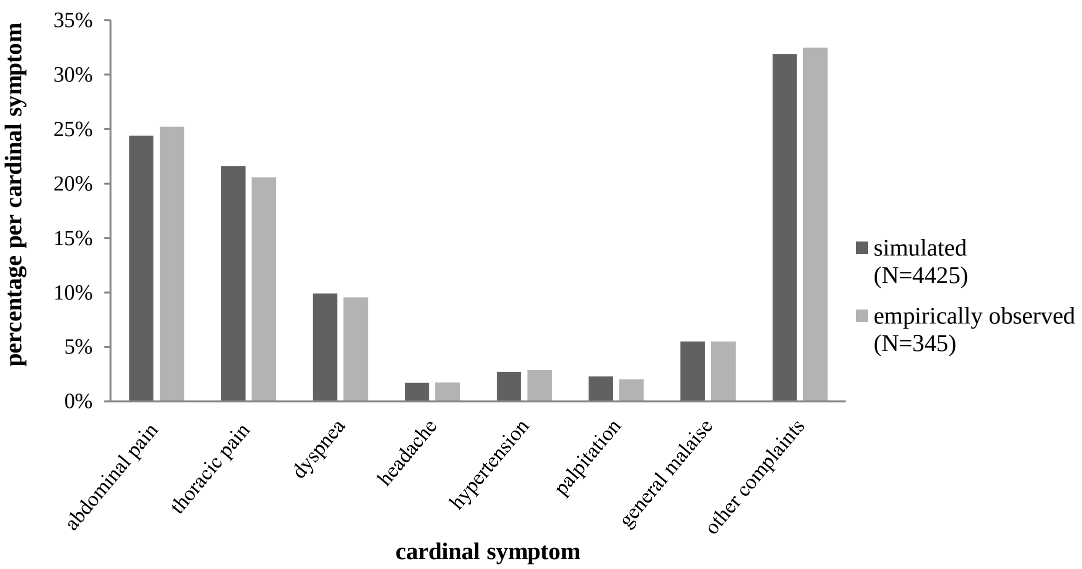

Figure 10: Comparison of patients' cardinal symptoms

As illustrated in Figures 8 – 10, patients' age, gender and ESI level have been reproduced by the simulation model with a deviation of less than 1%. The distribution of cardinal symptoms deviates by less than 2%. Therefore it can be assumed that these attributes are reproduced accurately by the simulation model.

After validating the patient related input data, the patients' waiting and treatment times are discussed in a next step.

Since the input variables for the simulation are generated randomly, the histograms of empirically observed and simulated values will never be identical. Nevertheless there are strong similarities concerning the shape of the distribution functions being studied.

Figure 11 illustrates a comparison of empirically observed and simulated LOS of patients visiting the emergency outpatient clinic for internal medicine. Patients' LOS is illustrated on the x-axis, whereas 30 minute time intervals have been chosen for plotting the data. The percentage of observations per time interval is shown on the y-axis. There are small deviations concerning the percentage of observations per time interval for empirically observed and simulated values. Nevertheless, the means of simulated and empirically observed values lie in the same time interval (90 – 120 minutes). In addition the median of patients' LOS is reproduced with a deviation of approximately 5%. Therefore it can be assumed that the model reproduces the real LOS in an adequate way.

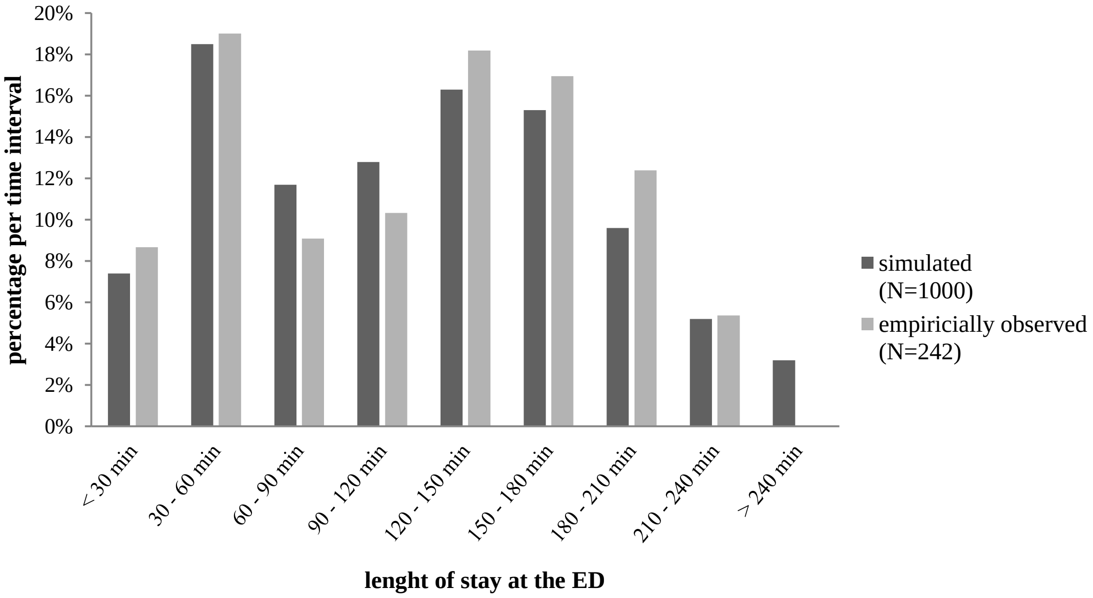

Figure 11: Comparison of LOS

As a patient's LOS consists of the waiting time and the treatment time, these components are now evaluated separately as well.

In the emergency outpatient clinic for internal medicine more than 70% of patients' LOS is waiting time only. A comparison between simulated and empirically observed total waiting time is given in Figure 12. The total waiting time – separated in time intervals with a range of ten minutes – is illustrated on the x-axis. The percentage of observations per time interval is shown on the y-axis. Both histograms have a similar shape. 49.20% of empirically observed, respectively 39.00% of simulated patients in total wait less than one hour. This share represents patients who are seen by a physician only once and do not have to wait for the discussion of certain test results. About 5% of all patients have to wait more than 3 hours, whereas this long waiting time is often caused by multiple diagnostic tests and the resulting waiting times.

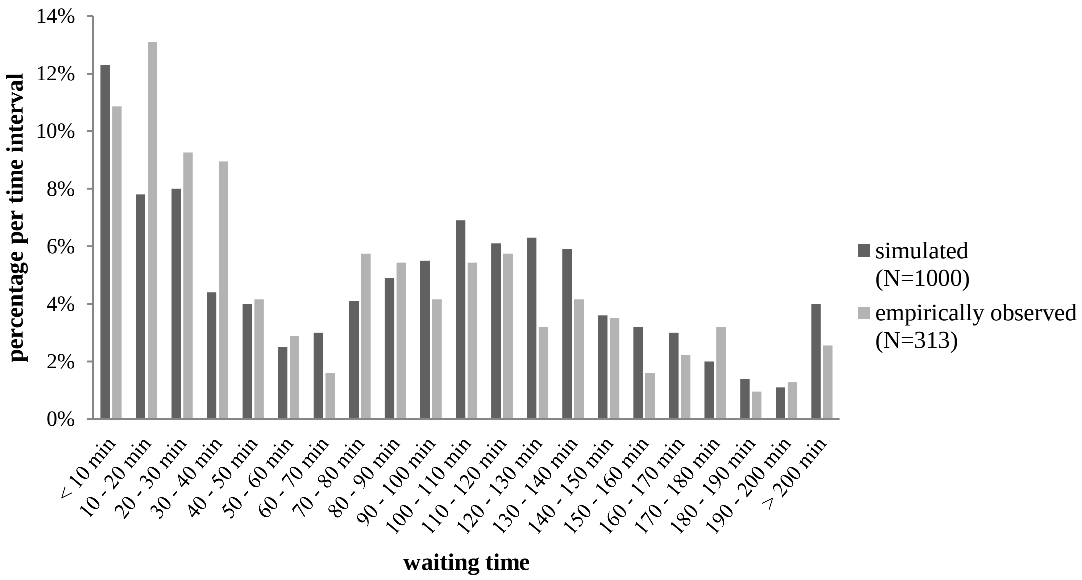

Figure 12: Comparison of total waiting times

The total waiting time of a patient can be split up into the waiting time for the first examination by a physician and the waiting time for discussing results, whereas the latter accounts for the biggest share of total waiting time.

Figure 13 compares the waiting time for the first examination by a physician. The waiting time is illustrated on the x-axis, whereas the chosen time intervals have a range of five minutes. The percentage of observations per time interval is shown on the y-axis. The simulation model reproduces the 5% confidence interval (CI) with a deviation of approximately 13%. As visualised in Figure 13 the simulated percentage of patients which are seen by a physician within 5 minutes is higher compared to empirical reference values. This deviation can be explained by the assumed behaviour of the administration clerk concerning the conditions that are crucial for bringing patient charts to the chart board. In the simulation model these conditions are strictly defined, whereas in reality unpredictable events, e.g. incoming phone calls, may extend the time the administration clerk needs to bring patient charts to the chart board and thus inform a physician about the arrival of a new patient. As these factors are not considered in the simulation model, the number of patients waiting less than 5 minutes exceeds the number of empirical observations. Besides this deviation the further shape of simulated and empirically observed distribution functions for the waiting time for a first examination by a physician are very similar. In both cases only 5% of all patients have to wait more than 75 minutes until they are seen by a physician.

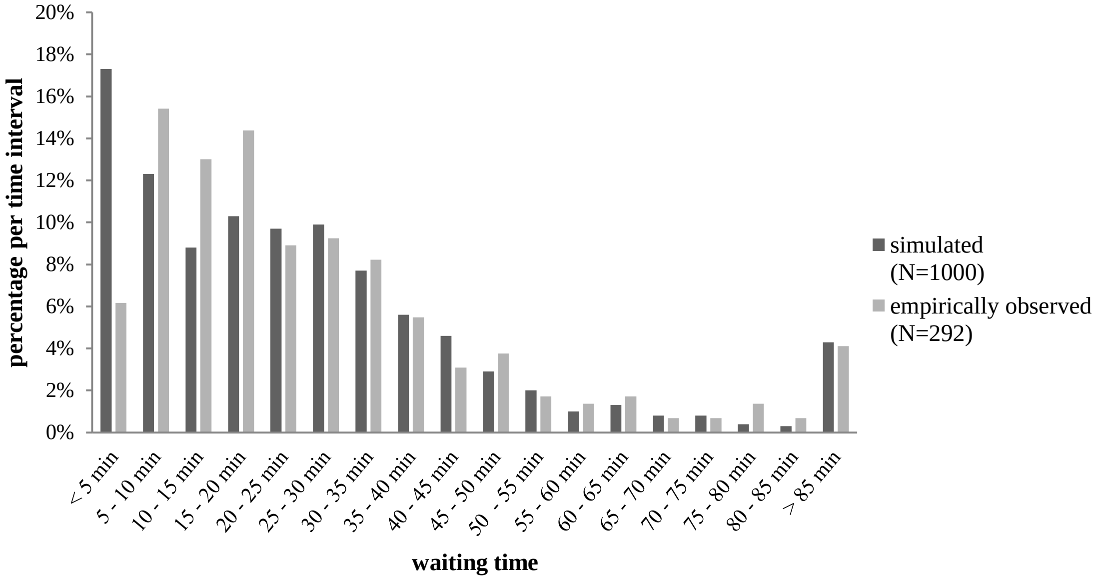

Figure 13: Comparison of waiting times for first examination by a physician

Referring to the waiting time for discussing results the median of simulated and empirically observed waiting times deviates by less than 5%. The distribution of waiting time for discussing results is visualized in Figure 14. The waiting time for discussing results is depicted on the x-axis. The percentage of observations per time interval is shown on the y-axis. Two peaks can be observed within the range of one and two hours. Patients waiting less than one hour are often treated medically and have to wait until the effects of medication arise. Patients waiting longer than one hour are mostly waiting for test results of blood tests or x-rays. As shown in Figure 14 the distribution functions of simulated and empirically observed values are very similar and thus lead to the assumption of a valid reproduction of real waiting times.

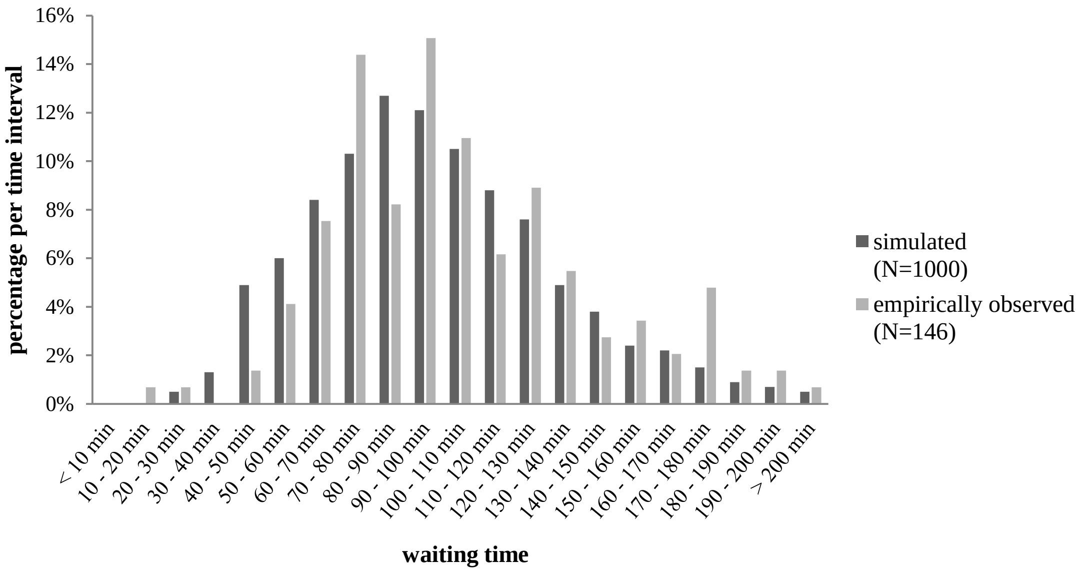

Figure 14: Comparison of waiting times for discussing results

Besides waiting times in the emergency outpatient clinic, the amount of time in which a patient is actually treated by a doctor was studied. The average treatment time of a patient in total is approximately 20 minutes and can be split up in time needed for the first examination by a physician and time needed for discussing results.

The average time needed for the first examination by a physician is illustrated in Figure 15. The time needed to examine a patient is illustrated on the x-axis and the percentage of observations per time interval is shown on the y-axis. The shapes of the distribution functions are very similar, with a peak in a treatment time between 10 to 15 minutes.

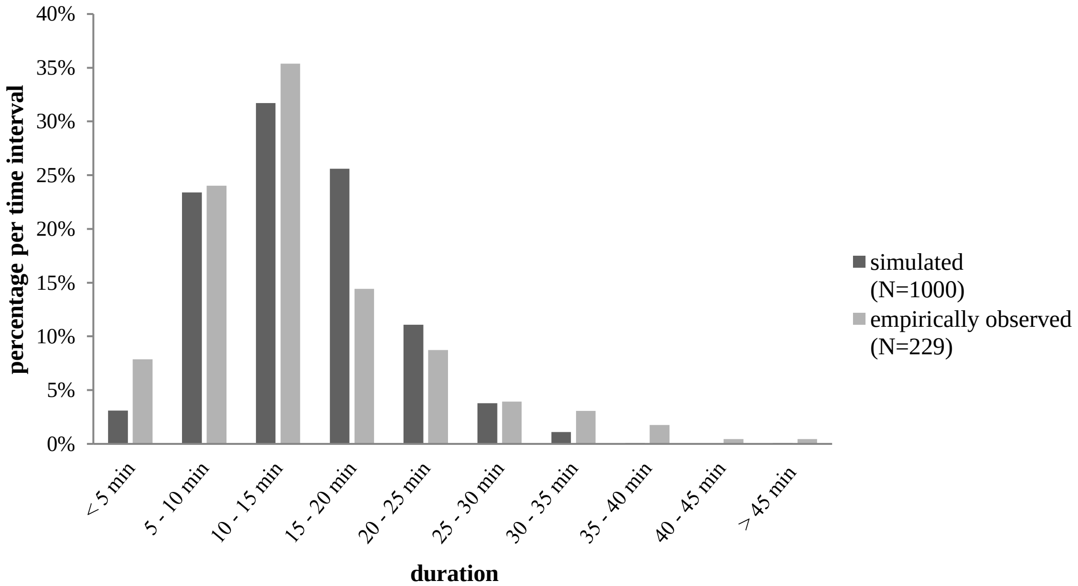

Figure 15: Comparison of duration of first examination by a physician

In the end a depiction of the distribution of the time needed for discussing results is given in Figure 16. The time needed for discussing results is depicted on the x-axis. The percentage of observations per time interval is shown on the y-axis. The median for this treatment step was reproduced with a deviation of only 5% and in both cases lies within the 4 to 6 minutes time interval.

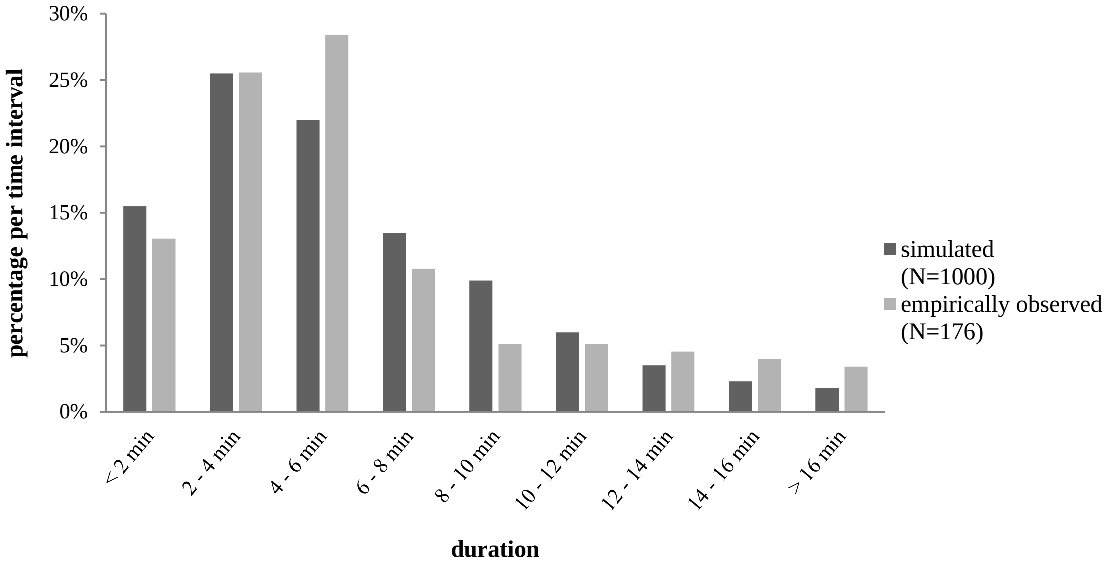

Figure 16: Comparison of duration of discussing results

Summarizing it can be stated that Figures 8 – 16 visualize the accurate reproduction of patient data as well as treatment and waiting times. In all cases the shapes of the distribution of empirically observed and simulated values are very similar.

After passing statistical and graphical tests for operational model validation it can be assumed that the distribution functions defined in Section 4 are a solid basis for the simulation model and that patient flow was implemented accurately. The model can now be used to evaluate the current ED performance, the average number of patients in the system and the current ED efficiency.

Besides an analysis of the current state at the ED, in the next section a peak hour analysis and a bottleneck analysis are performed in order to evaluate how the KPIs change during peak hours and periods with a high number of incoming patients.

5.3 Simulation Outcome

For analysing the current state at the emergency outpatient clinic for internal medicine, the main KPIs will now be discussed in detail.

Table 7 summarises the current average treatment and waiting times. All values are calculated based on a survey sample size of N = 1000 and denoted in minutes. The column 'mean' refers to the mean treatment or waiting times, whereas the 95% mean confidence interval is stated in the column 'mean CI'. In addition the boundaries for the 5% and 95% quantile are mentioned in the last two rows.

	mean	mean CI	5% quantile	95% quantile
LOS	119.18	± 4.22	27.49	225.93
total waiting time	85.91	± 3.94	4.66	189.75
waiting time for first examination by a physician	27.34	± 1.90	4.18	74.72
waiting time for discussing results	98.38	± 2.14	47.13	161.46
duration of the first examination by a physician	14.26	± 0.37	5.67	25.27
duration of discussing results	5.73	± 0.24	1.20	13.50

Table 7: Current waiting and treatment times

90% of all patients stay at the ED for between 27.49 and 225.93 minutes. Only 1% has to stay at the ED for more than 5 hours. This share consists mostly of those patients who suffer from heart problems and need periodical observation, repeated ECGs and blood tests. The long LOS thus results from the necessary observation time and waiting times for the results of repeated blood tests. The 5% of patients who leave the ED within 27.49 minutes are patients who are only seen once by a physician and are discharged right away.

The biggest share of the time a patient spends in the emergency outpatient clinic for internal medicine is waiting time, especially waiting time for discussing test results. The time needed to perform blood tests in the central laboratory is reflected in this waiting time. 90% of all patients have to wait between 47.13 and 161.46 minutes until all their test results are available. Thus, avoiding unnecessary blood tests could save resources and might lead to a reduction of average waiting times as well as the resulting LOS at the ED.

The time a patient has to wait for the first examination by a physician may vary as well. On average patients are seen by a physician within 27.34 minutes. In case all attending physicians are busy over a longer period of time, e.g. due to the elaborate treatment of a patient, this waiting time may increase. Nevertheless in 95% of all cases a patient gets in contact with a physician in less than 74.72 minutes.

Approximately 30% of a patient's time in the ED is time he or she actually receives treatment, but due to different clinical pathways depending on the cardinal symptom (see Table 3 on page 27), the average treatment time for the first examination by a physician varies in accordance to a patient's complaints.

Table 8 shows the average time for the first examination by a physician diversified according to the main cardinal symptoms. Mean treatment times (denoted in minutes) and the according cardinal symptoms are sorted in ascending order. The first examination by a physician is performed in the shortest period of time for patients with other complaints, followed by patients suffering from hypertension. Treatment of patients complaining about headache, on the contrary, takes the longest period of time.

cardinal symptom	**average time for first examination by a physician**	**mean CI**	**N**
other complaints	12.1822	± 0.3466	1000
hypertension	12.2958	± 0.9743	120
abdominal pain	13.7767	± 0.3612	1000
palpitation	13.9625	± 1.1407	102
thoracic pain	14.2184	± 0.3620	957
general malaise	14.7765	± 0.7744	244
dyspnoea	14.9562	± 0.5661	437
headache	15.7037	± 1.8511	75

Table 8: Time for first examination according to the cardinal symptoms

In order to prove the assumption that there are significant differences in mean treatment times depending on the cardinal symptom, the Mann-Whitney-U-test for unknown variances was performed for all combinations of cardinal symptoms.

The null hypothesis (H_0 = there is no significant difference in mean values) is rejected with a level of significance of $\alpha = 1\%$ in case the test statistic is outside of the 99% confidence interval -2.576 and +2.576. The results of this hypothesis test are summarized in Table 9.

Concerning some combinations of cardinal symptoms (e.g. other complaints and abdominal pain) the test statistic of the Mann-Whitney-U-test is outside the 99% confidence interval. The average time for treating patients with other complaints therefore differs significantly from the time needed to treat patients with abdominal pain. The time needed to treat a patient with hypertension differs significantly from the time needed to treat patients with dyspnoea, general malaise or headache.

In case a significant difference in mean values was proven statistically the values in Table 9 are printed in black. For those combinations where no significant difference in mean treatment times could be proven, the test statistic is printed in a lighter tone.

	other complaints	hypertension	abdominal pain	palpitation	thoracic pain	general malaise	dyspnoea
other complaints	-	-1.4450	-6.3933	-4.4697	-8.1691	-6.9736	-9.0315
hypertension	-1.4450	-	-1.5370	-0.6289	-2.3920	-3.3909	-3.6880
abdominal pain	-6.3933	-1.5370	-	-1.7814	-1.8666	-3.3364	-4.2630
palpitation	-4.4697	-0.6289	-1.7814	-	-0.9973	-0.6289	-0.4642
thoracic pain	-8.1691	-2.3920	-1.8666	-0.9973	-	-2.2595	-2.7995
general malaise	-6.9736	-3.3909	-3.3364	-0.6289	-2.2595	-	-0.1950
dyspnoea	-9.0315	-3.6880	-4.2630	-0.4642	-2.7995	-0.1950	-
headache	-5.4352	-3.7793	-3.7455	-2.1285	-3.2538	-1.8481	-2.2155

Table 9: Differences in treatment time according to cardinal symptoms

As shown in Table 9, there are significant differences in mean treatment times according to the cardinal symptoms. Some cardinal symptoms require a similar treatment and therefore the duration of the first examination by a physician does not differ significantly. Nevertheless it can be stated that the time needed to examine a patient does depend on his or her cardinal symptom.

Unlike the duration of the first examination by a physician, the time needed for discussing results does not depend on the main cardinal symptoms. Therefore the average time for this procedure stated in Table 7 is valid for all patients who receive this treatment. In 95% of all cases this procedure can be performed within 13.50 minutes.

5.3.1 Average Number of Patients in the System and Resource Utilization

The average number of patients in the emergency outpatient clinic and current ED efficiency was calculated based on 4420 observations.

Within the simulation runtime on average 44.2 patients visited the emergency outpatient clinic for internal medicine each day. Thereof 25% solely arrived during the peak hours between 16:00 and 20:00.

The average number of patients at the emergency outpatient clinic within a 24-hour period is 3.65. During peak hours this number increases by 47.40%. The high patient rush between 16:00 and 20:00 leads to an average number of 5.38 patients at the ED.

In both scenarios (24-hour period and peak hour period) approximately 70% of all patients are situated in the waiting hall. Thereof 30% have not yet been seen by a physician and thus are waiting for the first examination by a physician. The remaining 70% of the patients in the waiting hall are waiting for discussing certain test results.

Considering a 24-hour period the probability that more than 10 patients are situated in the ED at a certain point in time is approximately 1.70%. During peak hours this probability is almost four times as high and increases to 6.40%. On the contrary, the probability that less than 3 patients are at the ED is almost three times as high considering a 24-hour period compared to the peak hour period. During peak hours in only 10.97% of all cases, less than 3 patients are situated at the emergency outpatient clinic for internal medicine.

Referring to ED efficiency the utilization of the two available ED doctors within a 24-hour period is 31.10%. The two treatment rooms are occupied in 27.50% of the observed time interval. The utilization rate of ED physicians is in accordance with recent studies, showing that 20% to 30% of a physician's time is spent on direct patient care. The biggest part of a typical working day is spend on documentation, consultation and communication with other staff members, as well as other tasks which do not include direct contact to patients [37, 38, 39]. As the created simulation model considers mostly tasks of a physician that are related to direct patient care, it is not surprising that the utilization rate of the resource doctor lies within this range.

During peak hours, the utilization of physicians increases to 45.75%, the utilization of treatment rooms to 40.50%. Thus it can be stated that the higher amount of patients arriving in the afternoon is still manageable with the available resources. Moreover it should be taken into account that the average utilization rate of these resources is biased due to less patients arriving during the night.

Table 10 summarizes the main findings of the analysis of current ED operations. In addition to a separate analysis of the KPIs at any point in time for a 24-hour period and for the peak hours, the changes in KPIs resulting from an increase of patients arriving at the ED are stated in the column 'deviation'.

average number of patients	**24-hour period**	**peak hour**	**deviation**
waiting for first examination by a physician	0.80	1.10	+37.41%
waiting for discussing results	1.86	2.71	+45.70%
in the system	3.65	5.38	+47.40%
in the waiting hall	2.67	3.82	+43.07%
arriving at the ED per hour	1.84	2.76	+50.00%
ED efficiency	**24-hour period**	**peak hour**	**deviation**
utilization of doctors	31.10%	45.75%	+47.11%
utilization of treatment rooms	27.50%	40.50%	+47.27%

Table 10: Average number of patients in the system and ED efficiency

As summarized in Table 10 the resource utilization and the average number of patients at the emergency outpatient clinic for internal medicine increase during peak hours. It is assumed that also waiting times at the ED increase, when more patients arrive at the ED. Therefore the simulated waiting times of a 24-hour period have been compared to the outcome during peak hour.

Mann-Whitney-U-tests for unknown variances have been performed in order to check whether there are significant increases in waiting times or patients' LOS during peak hours. The assumption that there are no significant differences in mean waiting times can be rejected with a level of $\alpha = 1\%$ in case the test statistic – stated in the column 'U-test' in Table 11 – is outside the interval -2.576 and +2.576.

	mean (24 hour)	mean (peak hour)	U test	deviation
LOS	119.1812	117.4134	-0.0075	-1.48%
total waiting time	85.9062	86.5538	-1.3539	+0.75%
waiting time for first examination by a physician	27.3397	23.7021	-0.4955	-13.31%
waiting time for discussing results	98.3785	98.3984	-0.3266	+0.02%

Table 11: Comparison of mean KPIs on a 24-hour basis and during peak hours

As shown in Table 11, the test statistics for all KPIs lie within the 99% confidence interval. Thus the null hypothesis cannot be rejected and it can be stated that there are no significant differences in mean waiting times.

It is assumed that the available resources are capable to meet the demand during peak hours. Only resource utilization increases, whereas waiting times in the ED stay the same. In order to evaluate the effects of a significant increase of arriving patients per day, the next section focuses on the results of the bottleneck analysis.

5.4 Bottleneck Analysis

Since the results of the peak hour analysis showed no significant changes in waiting times due to the general fluctuations in the number of arriving patients over the day, in a next step a bottleneck analysis was performed in order to evaluate at which point in the system the patient flow will be hindered first in case of a significant increase in arriving patients.

Therefore the number of patients arriving at the ED per time interval was increased systematically. At the beginning an increase of arriving patients by 10% was simulated. This coefficient was then increased by 10% until the number of arriving patients was doubled.

Figure 17 illustrates the effects on waiting times and LOS due to a higher amount of patients arriving at the ED. The x-axis shows the percentage increase of patients, the resulting waiting times and patients' LOS are depicted on the y-axis. At first all waiting times, as well as LOS stay nearly constant although the number of patients arriving at the ED increases, but at a certain level all KPIs increase significantly.

E.g. the average LOS of a patient starts to increase slowly (by 3.74%) as soon as the number of patients arriving at the ED is increased by 40%. A significant increase in mean LOS can be proven as soon as the number of arriving patients is increased by 70%. In this scenario, the average LOS increases by 7.30%. In case of a 100% increase of patients' LOS increases by 23.05%.

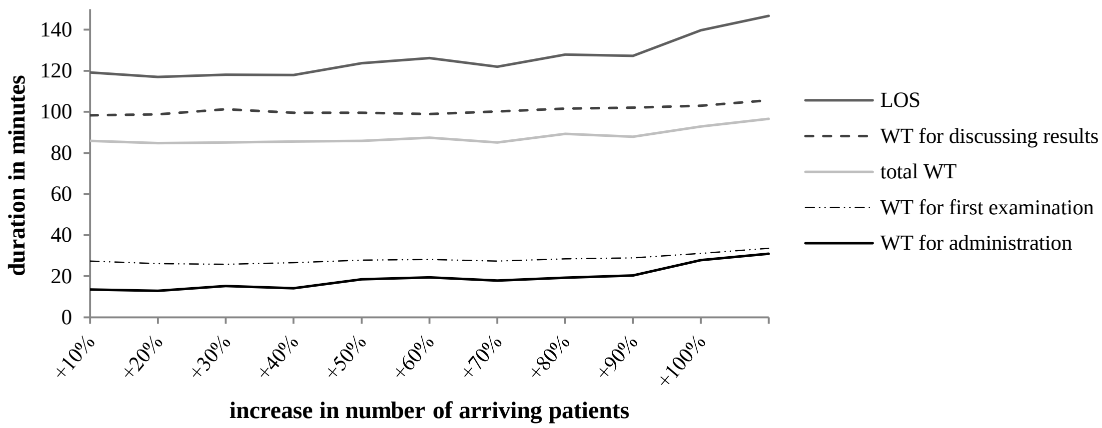

Figure 17: Bottleneck analysis: absolute changes in waiting times

Waiting times for the first examination by a physician (WT for first examination) starts to rise significantly as soon as the number of patients is increased by 40%. Detailed results of the Mann-Whitney-U-test for unknown variances, that was used to prove significant differences in mean waiting times and LOS, can be found in Table 30 in the Appendix. The test statistic of this hypothesis test is stated in the row 'U-test'.

It should be noted that the waiting times in the emergency outpatient clinic for internal medicine react quite slowly to an increase of arriving patients. As the graphical interface of the simulation model (see Figure 18 and Figure 19) showed that the number of patients waiting for the administration at the front desk increases significantly in case of higher patient rush, it is assumed that in case of an increasing demand a bottleneck first occurs at the front desk.

The graphical interface of the simulation model during current patient rush is illustrated in Figure 18. Figure 19, on the contrary illustrates a simulation run considering an increase of arriving patients by 100%. Patients who are situated at the front desk either get administrated or are waiting for the administration. Those patients which are situated in the waiting hall and are coloured in white are waiting for the first examination by a physician, those painted in black are waiting for discussing results. Patients which are situated in one of the treatment rooms are examined by a physician. It can be seen, that in the second scenario far more patients are in the system and waiting for any procedure. In addition there are far more patients waiting for the administration at the front desk in case of an increase of patients by

100%. This led to the assumption that the administration at the front desk leads to a bottleneck in the patient flow.

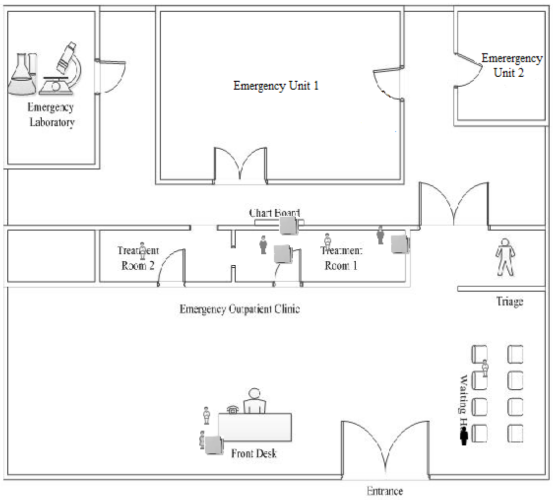

Figure 18: Current state simulation

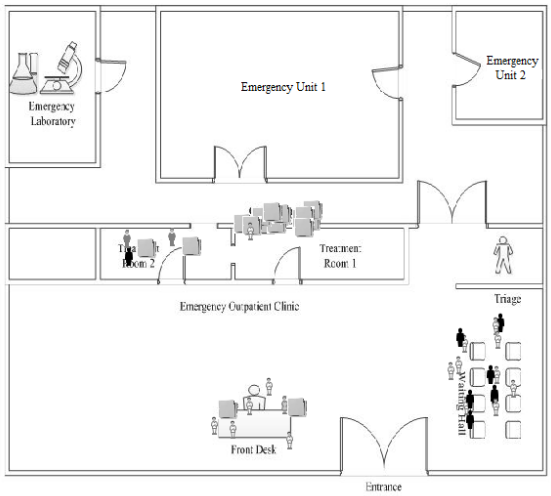

Figure 19: Increase of patients by 100%

In order to prove if the bottleneck at the front desk leads to unnecessary long waiting times at the ED, it was analysed if a patient’s waiting time for the first examination by a physician solely results from the bottleneck at the front desk, or if patients would have to wait in the waiting hall anyway as there are no doctors available when they arrive.

Therefore the probability that the administration clerk does not carry patient charts to the chart board because there are patients waiting for administration at the front desk while at least one doctor would be idle and could already treat new patients, was evaluated. In case these conditions are true patients would only have to wait longer before they are examined by a physician as their patient chart is still at the front desk. From now on this scenario will be called a ‘real bottleneck’, while a situation where patients would have to wait anyway as all doctors are busy is called ‘no real bottleneck’.

Table 12 summarizes the probability that a real bottleneck at the front desk occurs for all scenarios considered in the bottleneck analysis and the peak hour analysis. The column ‘no real bottleneck’ shows the proportion of patients who would have to wait anyway as all doctors are busy when they arrive. The numbers stated in brackets shows how many patients on average are waiting in the waiting hall in case of a real bottleneck and in case of no real bottleneck. In the current system in 3.57% of all cases a real bottleneck occurs, considering a whole day at the ED. During peak hours a real bottleneck occurs in 5.71%. In case there is no real bottleneck at the front desk on a 24-hour basis on average 3.66 patients are waiting in the waiting hall, during peak hours on average 4.47 patients wait there.

	real bottleneck	no real bottleneck	patients per day	patients per hour
current state	3.57% (2.90)	96.43% (3.66)	44.20	1.84
peak hour	5.71% (3.79)	94.29% (4.47)	66.21	2.76
+10%	4.10% (3.15)	95.90% (3.88)	48.77	2.03
+20%	5.50% (3.63)	94.50% (4.42)	54.77	2.28
+30%	5.64% (3.90)	94.36% (4.47)	58.56	2.44
+40%	7.46% (4.25)	92.54% (5.05)	63.11	2.63
+50%	7.46% (4.61)	92.54% (5.24)	68.23	2.84
+60%	8.08% (5.01)	91.92% (5.52)	72.32	3.01
+70%	9.02% (5.72)	90.98% (6.17)	79.18	3.30
+80%	8.11% (5.76)	91.89% (5.91)	80.62	3.36
+90%	9.13% (6.27)	90.87% (6.18)	85.03	3.54
+100%	9.18% (6.62)	90.82% (6.51)	89.64	3.74

Table 12: Probability of a real bottleneck at the front desk

As in case of a 100% increase of patients arriving at the ED every tenth patient faces a real bottleneck, it can again be assumed, that a significant increase in arriving patients cannot be managed by the current process of administration at the front desk without leading to a delay in the patient flow. Due to this development waiting times for the administration at the front desk will be considered in the bottleneck analysis and in the 'what-if' analysis, although based on certain assumptions made during model implementation this waiting time was not evaluated in the analysis of the current state.

The waiting time for administration at the front desk increases by 12.50% in case of an increase of arriving patients by 20%. In case the number of patients at the ED doubles, the average waiting time for administration even increases by 128.27%. It is assumed, that due to this bottleneck waiting times for treatment steps afterwards are not that sensitive to the increasing number of patients, as the process flow is already delayed.

Figure 20 illustrates how the waiting times being studied evolve when the demand of arriving patients is increased systematically by comparing the increase of arriving patients and the relative increase in waiting times and LOS. It can be seen that the waiting time for administration is far more sensitive to changes in the number of arriving patients and thus increases relatively strong in case of an increasing demand. All other waiting times stay nearly constant at first and start to increase rapidly when the number of patients arriving at the ED is increased by 80% or more.

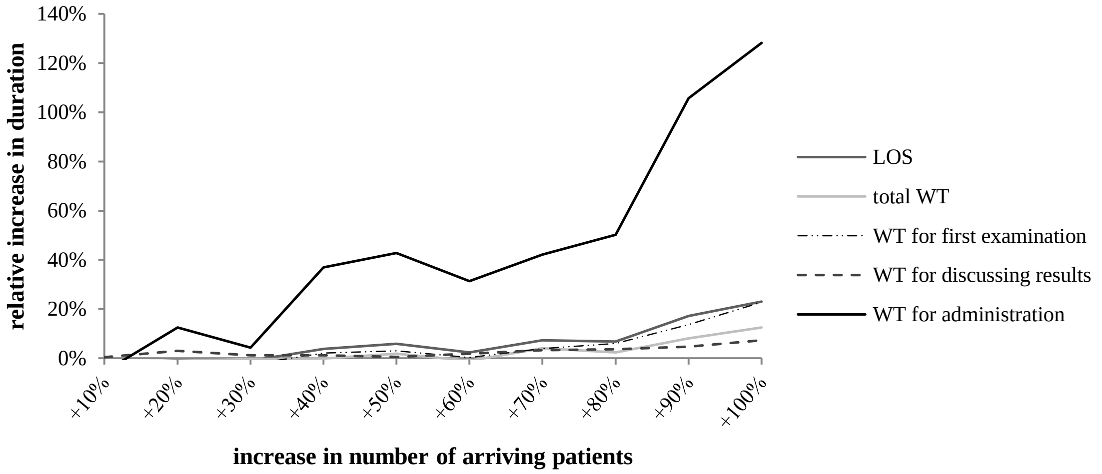

Figure 20: Bottleneck analysis: relative changes in waiting times

Although the average waiting times for single process steps – except the waiting time for administration at the front desk – are quite robust, the average numbers of patients waiting for these process steps react quickly when the number of arriving patients increases.

Figure 21 illustrates how the average number of patients in the system changes when the number of patients arriving at the ED is increased systematically. The increase of patients arriving per day is shown on the x-axis. The y-axis illustrates the relative increase of patients at the ED. This figure gives evidence for the long delay at the front desk, as well.

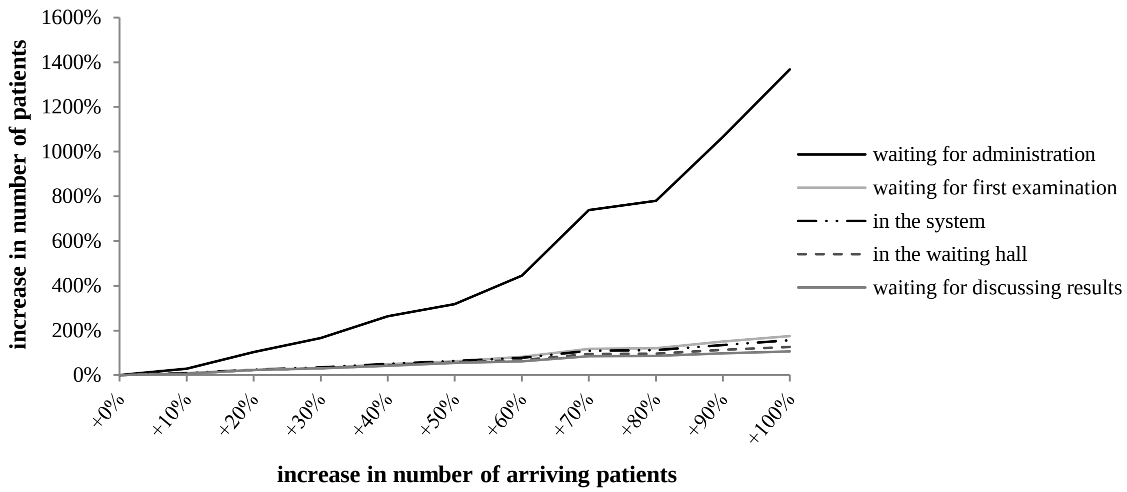

Figure 21: Bottleneck analysis: relative changes in number of patients

While the average number of patients waiting for the first examination by a physician and discussing results increases by 8.48% and 6.92% in case of an increase of patients by 10%, the average number of patients waiting for administration increases by 29.13%. The graph illustrating the effect on the number of patients waiting for administration shows a faster increase, compared to the development of the other waiting times. This effect amplifies the assumption that a bottleneck first occurs at the front desk.

The increasing number of patients in the system is also reflected in the utilization rate of the resources doctor and treatment room. The more patients arrive at the ED, the higher they are utilized. Until an increase of patients by 80% the average utilization increases disproportionately. As soon as the number of patients is increased above this level, the increase in average utilization declines. It can be assumed that this effect occurs, as the available resources are not able to meet the high demand any longer.

The evolvement of resource utilization is shown in Figure 22. The slope of the lines illustrating the utilization of resources starts to decline when the resources doctor and treatment room are on average utilized by 56.20% and 49.70%. This utilization rates occur as soon as the number of patients arriving at the ED is increased by 80%. As in this scenario the resource utilization increases to 81.20% and 72.80% during peak hours, it can be assumed, that the resources are overallocated and the increase in utilization thus starts to decline.

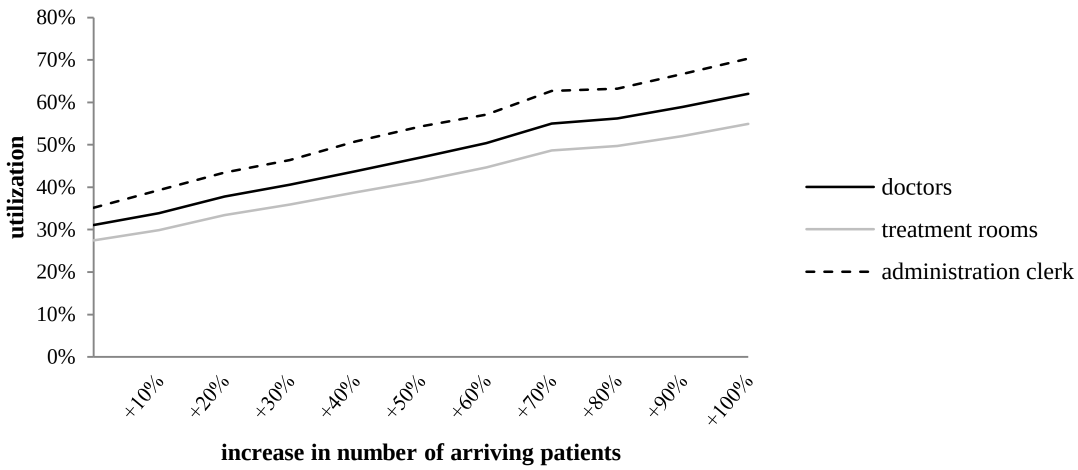

Figure 22: Bottleneck analysis: changes in resource utilization

Summarizing it can be stated, that as soon as the number of patients arriving at the ED increases significantly, a bottleneck will first occur at the front desk. All other waiting times and patients' LOS do not change significantly at first. Nevertheless the results of the bottleneck analysis have to be interpreted carefully due to the simplifications and assumptions that have been made during model implementation.

In the simulation model the process step administration also includes the time needed to perform a triage. Thus the real duration of this step in the patient flow would be lower. The frequency of carrying patient charts to the chart board is fixed in the simulation model and may vary in reality. Despite these assumptions a bottleneck was observed at the front desk although only patients for the emergency outpatient clinic of internal medicine are considered in this study. In reality also patients of all other specialty departments of the ED are seen at the triage and the front desk, whereas the real demand for this process steps would be significantly higher compared to the simulated situation.

Therefore there are reasons to assume that the administration at the front desk will lead to significantly higher waiting times in case of an increasing number of arriving patients. In order to make a clear statement of whether and in which case there is a real bottleneck at the front desk further examinations would be necessary.

For the further research in this master thesis it is assumed, that the bottleneck at the front desk will occur in case of an increasing demand. Among other things, the next section focuses on the question of how the bottleneck at the front desk could be removed and how this would affect the model outcome.

6 What-if Analysis

In order to analyse how the simulation outcome changes when independent input variables or the general process flow are modified a 'what-if' analysis was applied. This technique can be used to build different scenarios and evaluate how sensitive the outcome is to small changes in input variables.

Three different scenarios have been considered in the 'what-if' analysis. Scenario A focuses on a change in the general process of the administration at the front desk. Scenario B deals with the effects of changing the clinical pathways in the emergency outpatient clinic. Scenario C analyses the effects of changing the resource levels of doctors and treatment rooms.

In this section the setup and the outcome of the performed 'what-if' analysis and the corresponding scenarios are discussed in detail.

6.1 Scenario A

Based on the results of the bottleneck analysis the main aim of the first scenario of the 'what-if' analysis was to evaluate reasons for long waiting times at the front desk in case of an increasing demand of patients. Therefore it was decided to change the general process flow and evaluate the effects on the model outcome.

6.1.1 Setup of Scenario A

In the current process flow the administration clerk faces a dual task of administrating new patients on the one hand and carrying patient charts to the chart board behind the treatment rooms on the other hand. As soon as the number of patients arriving at the ED increases by more than 20% the administration clerk is not capable to meet the demand any longer and waiting times before this process step increase significantly.

Therefore in Scenario A it is assumed that the administration clerk only is responsible for administrating new patients and no longer has to carry patient charts to the chart board behind the treatment rooms. This could e.g. be achieved by implementing a computer system that allows the triage nurse and the administration clerk to immediately put the recorded patient data in a data base. Physicians may call up the patient data from their computer screens right after a patient's arrival. By printing out the according data a patient chart could be compiled within the treatment rooms. Thus the administration clerk would no longer be obliged to carry patient charts to the chart board and the former time lack between the arrival of a new patient at the ED and the moment a doctor gets informed about it could be removed.

All other assumptions and input variables of the created model, as well as the simulation design have been unchanged and the simulation was run with this new assumption. The results will be outlined in the next subsections and show whether changing the process flow at the front desk e.g. by substituting the current patient charts by computerized patient charts would affect the ED performance.

6.1.2 Waiting Times and Length of Stay

In a first step the average waiting times and patients' LOS have been evaluated. All KPIs are calculated based on a survey sample size of N = 1000 and denoted in minutes.

Table 13 summarizes the mean values of waiting times and LOS as well as the lower and upper 5% quantile for these KPIs of Scenario A. In order to allow an easy comparison of the outcome in current state and under Scenario A, the results of the analysis of the current state are stated in brackets behind the corresponding values.

	mean	mean CI	5% quantile	95% quantile
LOS	96.12 (119.18)	±3.64 (± 4.22)	21.19 (27.49)	189.93 (225.93)
total waiting time	65.28 (85.91)	±3.37 (± 3.94)	4.16 (4.66)	151.29 (189.75)
waiting time for first examination	6.04 (27.34)	±0.24 (± 1.90)	3.95 (4.18)	12.88 (74.72)
waiting time for discussing results	98.40 (98.38)	±2.28 (± 2.14)	49.16 (47.13)	159.48 (161.46)

Table 13: Scenario A: Summary of mean KPIs

In case the process flow at the front desk is changed in a way that removes the time lack between the two process steps administration and first examination by a physician, 90% of all patients stay at the ED between 21.10 and 189.93 minutes. In the current system the same share of patients leaves the ED within 27.49 and 225.93 minutes. In addition to the decrease in LOS, the waiting time for the first examination by a physician could be decreased by changing the process flow. 5% of all patients would be seen by a physician within 3.95 minutes in case the administration clerk is not obligated to carry patient charts to the chart board. In the current system the same share of patient is seen within 4.18 minutes. Despite the reductions in LOS and the waiting time for the first examination by a physician, the average waiting time for discussing results stayed nearly unchanged. The total waiting time could be reduced due to the decrease in the waiting time for the first examination by a physician, though.

In a next step the mean KPIs of Scenario A have been compared to the current ED performance, in order to prove if a significant reduction of waiting times could be achieved by changing the process flow.

Table 14 summarizes how waiting times respond to the change in the process of administration. Current mean waiting times are stated in the column ‘current state’, whereas the mean waiting times resulting from the ‘what-if’ analysis can be found in the column ‘Scenario A’. Mann-Whitney-U-tests for unknown variances have been performed in order to analyse whether there are significant differences in mean waiting times in the current state and the ‘what-if’ scenario. With a level of significance of $\alpha = 1\%$ a significant difference in mean waiting times can be assumed in case the test statistic lies outside the interval -2.576 and +2.576. The corresponding test statistics for this hypothesis test are stated in the column ‘U-test’.

	current state	**Scenario A**	**U-test**	**deviation**
LOS	119.1812	96.1177	-7.9065	-19.35%
total waiting time	85.9062	65.2849	-8.6495	-24.00%
waiting time for first examination by a physician	27.3397	6.0374	-26.7171	-77.92%
waiting time for discussing results	98.3785	98.3984	-0.6900	+0.02%
waiting time for administration	13.5492	11.6707	-3.2430	-13.86%

Table 14: Scenario A: Comparison of waiting times

As shown in Table 14 the average LOS, total waiting time, the waiting time for the first examination by a physician, and the waiting time for administration could be decreased significantly by changing the process flow. Patients’ LOS could be decreased by 19.35%, whereas the total waiting time could be decreased by 24.00%. The strongest effect is observable concerning the waiting time for the first examination by a physician. This waiting time could be reduced by 77.92%, which leads to the assumption that the current waiting times for the first examination by a physician are strongly dependent on the time lack which results from the necessity that an administration clerk carries patient charts to the chart board behind the treatment rooms.

The waiting time for discussing results is the only KPI that did not change significantly. It can be assumed, that this waiting time mostly results from the delay time for blood tests in the central laboratory and thus cannot be reduced by changing the process flow in the emergency outpatient clinic for internal medicine.

After discussing the effects of the changes in the process flow made in Scenario A on the average waiting times and LOS, in a next step the effects on the average number of patients in the system and on resource utilization are evaluated.

6.1.3 Average Number of Patients in the System and Resource Utilization

In Scenario A on average 2.99 patients are situated in the emergency outpatient clinic for internal medicine. During peak hours this number increases to 4.40. On average there are 2.04 patients in the waiting hall. Thereof 91.18% are waiting for discussing results and only 8.82% have not been seen by a physician yet. During peak hours, the number of patients in the waiting hall increases to 2.96, whereof still more than 90% are waiting for discussing their test results.

Table 15 gives an overview of how the average number of patients in the system changes due to the adaptations in the process flow, by comparing the average number of patients in the current system to the average figures under Scenario A. The values stated in Table 15 represent the average observations of a whole day at the ED.

average number of patients	**current state (24-hours)**	**Scenario A (24-hours)**	**deviation**
waiting for first examination by a physician	0.80	0.18	-77.75%
waiting for discussing results	1.86	1.86	0.00%
in the system	3.65	2.99	-18.00%
in the waiting hall	2.67	2.04	-23.71%
waiting for administration	0.10	0.09	-17.48%
ED efficiency	**current state (24-hours)**	**Scenario A (24-hours)**	**deviation**
utilization of doctors	31.10%	31.10%	0.00%
utilization of treatment rooms	27.50%	27.50%	0.00%
utilization administration clerk	35.20%	27.20%	-8.00%

Table 15: Scenario A: Comparison of average number of patients and ED efficiency

The average number of patients in the system could be reduced by 18.00% in Scenario A, while the average number of patients waiting for the first examination by a physician could be decreased by 77.75% in case the ED physicians would be able to call up patient data from a data base immediately. Although the average number of patients waiting for discussing results stayed unchanged, the average number of patients in the waiting hall could be decreased by almost one fourth.

The utilization of the resource administration clerk could be decreased by 8% in case he or she is no longer obligated to carry patient charts to the chart board. The resource utilization of the resources doctor and treatment room stayed unchanged, as the adaptations to the process flow do not influence the workload of physicians. Thus it can be assumed that the reduction in waiting times solely results from the adaptations to the system and reduces the workload of administration clerks without increasing the utilization of physicians.

As a conclusion it can be stated that besides a reduction of waiting times, also the average number of patients in the system could be decreased significantly by removing the time lack between the arrival of a new patient at the ED and the moment when a physician gets informed about it. This improvement could be achieved without increasing the utilization of the available resources, e.g. by implementing a computer system that substitutes the current system, where administration clerks have to carry patient charts to the chart board.

As the results stated above solely refer to a whole day at the emergency outpatient clinic for internal medicine and do not consider the general fluctuations in the number of arriving patients over the day, in a next step a peak hour analysis was performed. It shall be shown if the improvements in ED performance are still valid in times of higher patient rush.

Table 16 summarizes the main findings of the peak hour analysis of Scenario A by comparing current ED performance during peak hours and the results of the ‘what-if’ analysis. It can be seen that the improvements in ED performance are also valid during peak hours. The deviations of the mean KPIs are very similar to those observed over a 24-hour period. E.g. the average number of patients waiting for the first examination by a physician could be decreased by almost 75%, while the utilization of doctors and treatment rooms nearly stayed unchanged and the utilization of the administration clerk could even be reduced.

average number of patients	current state (peak hour)	Scenario A (peak hour)	deviation
waiting for first examination by a physician	1.10	0.28	-74.27%
waiting for discussing results	2.71	2.68	-1.25%
in the system	5.38	4.40	-18.20%
in the waiting hall	3.82	2.96	-22.51%
waiting for administration	0.25	0.18	-30.71%
ED efficiency	**current state (peak hour)**	**Scenario A (peak hour)**	**deviation**
utilization of doctors	45.75%	45.10%	-0.65%
utilization of treatment rooms	40.50%	39.80%	-0.70%
utilization of administration clerk	53.10%	39.70%	-13.40%

Table 16: Scenario A: Comparison of peak hour performance

In order to prove if waiting times and patients' LOS change significantly during peak hours the Mann-Whitney-U-test for unknown variances was performed. The null hypothesis (H_0 = there is no significant difference in mean values) can be rejected with a level of significance of α= 1% in case the test statistic (stated in the column 'U-test) lies outside the 99% confidence interval of - 2.576 and +2.576. Table 17 summarizes the results of the comparison of waiting times during peak hours in the current system and under Scenario A. Similar to the results of the peak hour analysis of the current system, waiting times and LOS do not increase significantly during peak hours. Thus the changes in the process of administration still lead to improvements in ED performance during peak hours.

	24-hour period	peak hour	U-test	deviation
LOS	96.1177	93.8482	-0.7825	-2.42%
total waiting time	65.2849	62.3679	-1.1288	-4.68%
waiting time for first examination by a physician	6.0374	6.2910	-1.7416	+4.03%
waiting time for discussing results	98.3984	100.1455	-1.4609	+1.74%

Table 17: Scenario A: Changes in mean KPIs during peak hours

All in all changing the process flow, in a way that removes the time lack between the arrival of a new patient and the moment a doctor gets informed about it, leads to a positive effect on waiting times and LOS in case of current patient demand.

In a next step it shall be analysed how the system reacts when the number of patients arriving at the ED is increased systematically.

6.1.4 Bottleneck Analysis of Scenario A

By performing a bottleneck analysis it was evaluated if the former detected bottleneck at the front desk could be removed due to the changes in the process flow. Therefore the number of patients arriving at the ED has been increased systematically by 10% until the number of patients per time interval has been doubled. The changes in waiting times and LOS are outlined as follows.

Figure 23 shows how the average waiting times and LOS evolve due to the increase of arriving patients. Waiting times for all process steps hardly react to the increase of patients at the beginning, but when the number of patients arriving at the ED increases above a certain level a significant increase in waiting times can be observed.

Similar to the results of the bottleneck analysis of the current state, the waiting time for administration is the first to show a significant increase in mean waiting times. In case the number of patients arriving at the ED is increased by 30% the waiting time for administration increases by 10.20%. In the current system an increase of patients by 20% would be sufficient to increase the average waiting time by this share.

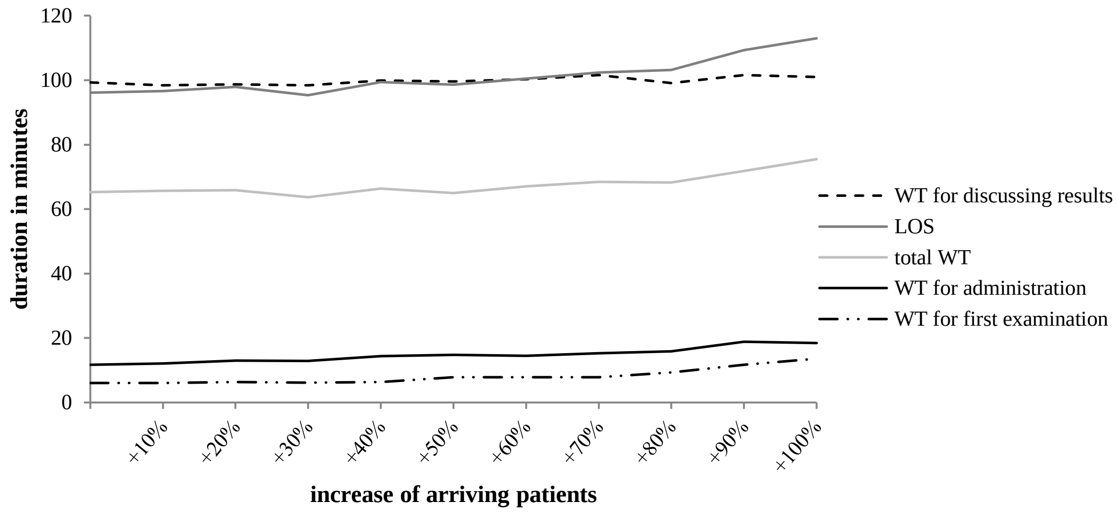

Figure 23: Scenario A: absolute changes in waiting times

Contrary to the current system, the mean waiting times for the first examination by a physician are more sensitive to an increase of patients in Scenario A. As soon as the number of patients arriving at the ED is increased by 50%, a significant increase in waiting time by 28.88% can be observed. In the current system the waiting time for the first examination by a physician increases only by 2.98% in case 50% more patients arrive.

LOS again is quite robust to the higher demand of patients. A significant increase can only be observed in case of an increase of patients by 70% or more. The total waiting time and the waiting time for discussing results increase significantly initially when the number of patients arriving at the ED is increased by 90%.

Numerical results of the bottleneck analysis of Scenario A can be found in detail in Table 31 in the Appendix.

For better understanding of how the waiting times in the ED evolve due to the higher patient demand Figure 24 illustrates the relative change in waiting times and LOS. Compared to the current situation at the ED, Scenario A shows a slower increase in the average waiting time for administration. The waiting time for the first examination by a physician, on the contrary, increase faster. All in all the changes in the process flow lead to a smoother increase in waiting times compared to the development of the current system.

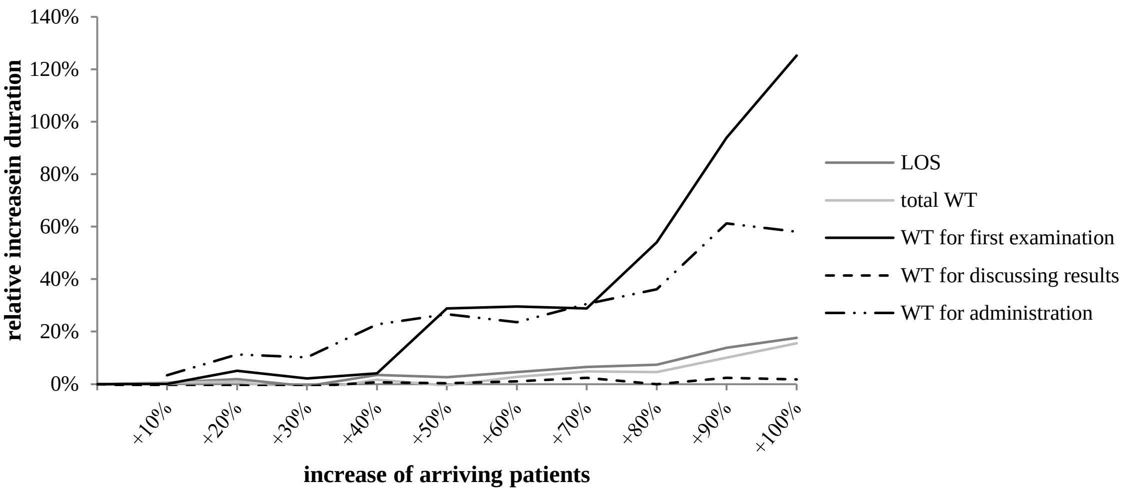

Figure 24: Scenario A: relative changes in waiting times

The same is valid for the average number of patients waiting and being in the system. While the average number of patients waiting for administration increases less rapid, the average number of patients waiting for the first examination by a physician increases stronger. This effect is visualized in Figure 25. It can be seen that the average number of patients waiting for discussing results does not increase differently compared to the current situation.

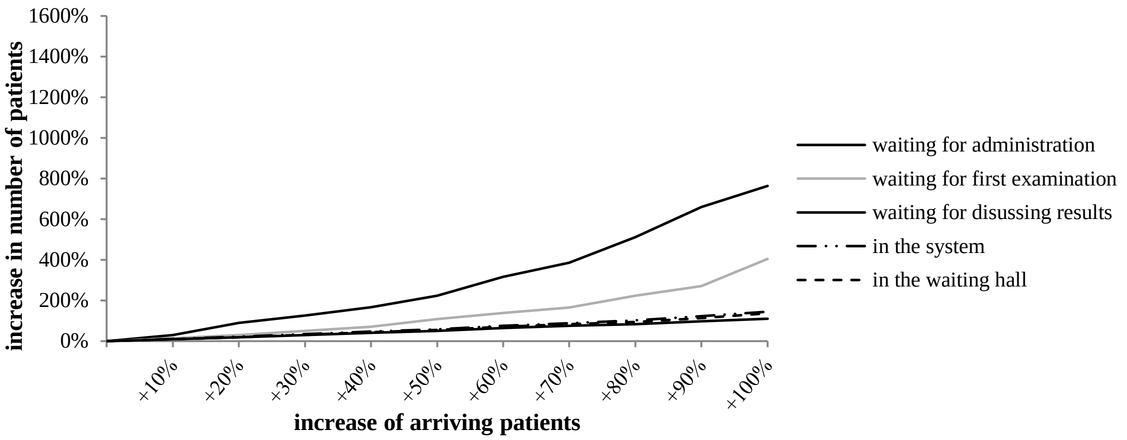

Figure 25: Scenario A: relative changes in number of patients

Referring to resource utilization Figure 26 shows that the utilization of doctors and treatment rooms does not increase stronger than in the current system. The utilization of the administration clerk can even be reduced significantly compared to the current state.

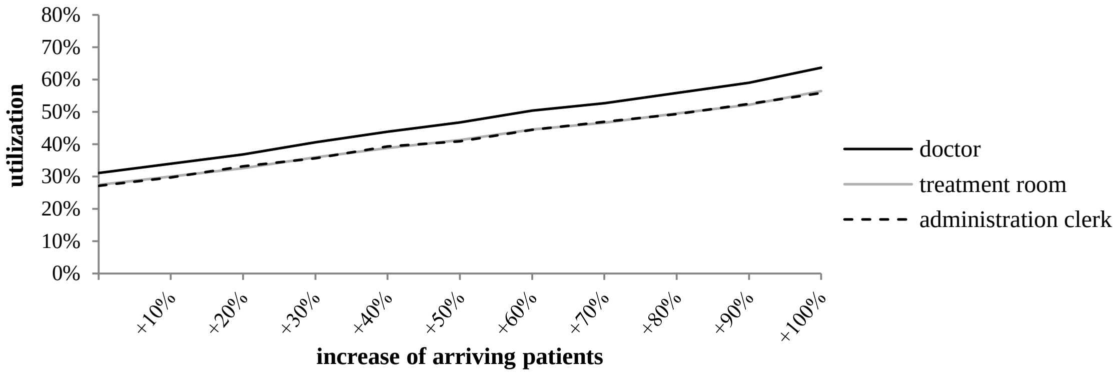

Figure 26: Scenario A: changes in resource utilization

Summarizing it can be stated that by removing the time lack between the arrival of a new patient at the ED and the moment a physician gets informed about it – e.g. by implementing a computer system that substitutes the necessity that the adminsitration clerk carries patient charts to the chart board behind the treatment rooms – the average waiting time for the first examination by a physician, average LOS and average total waiting time could be decreased significantly.

Changing the process flow the ED performance could be improved without the use of additional staff or a higher utilization of existing staff. Nevertheless further research concerning the efficiency of such a change in the process flow would be necessary in order to make a clear suggestion concerning an adaptation to the general process flow.

6.2 Scenario B

The focus of Scenario B lies on the question ‘what if ED physicians never write ECGs, take blood samples or prepare and deliver drugs?’

Thus in the following subsection it is analysed how changing clinical pathways in a way that allows ED nurses or medical students to perform the upper mentioned treatment steps would affect the ED performance. In addition it is measured how much time ED physicians could save in case they do no longer perform these treatment steps on their own.

6.2.1 Setup of Scenario B

In the current system all treatment steps are solely performed by ED doctors. This assumption was dropped in Scenario B. Thus from now on ED nurses or medical students always write ECGs, take blood samples and prepare and delivers drugs. All other treatment steps are still performed by ED physicians.

The treatment steps mentioned above have been removed from the clinical pathway depicted in Figure 6 on page 34. It is assumed that a patient receives treatment from ED nurses or medical students either in the waiting hall or in the corridor behind the treatment rooms for internal medicine during his or her waiting time or during the first examination by a physician. In the latter case a doctor would simultaneously perform other treatment steps, e.g. conducting a patient history or filling out forms, while a nurse or a medical student delivers the treatment.

All other assumptions and input variables from the current state simulation have been retained. In addition the changes in the process flow from Scenario A have been made undone so that again an administration clerk has to carry patient charts to the chart board behind the treatment rooms.

The effect of changing the clinical pathways on the treatment time of a patient, as well as the average waiting times and the LOS are outlined in detail as follows.

6.2.2 Treatment Times, Waiting Times and Length of Stay

In case a doctor is no longer obligated to write ECGs, take blood samples or prepare and deliver drugs, the time he or she spends on treating a patient could be reduced significantly.

The current average time needed for the first examination by a physician is 14.26 minutes. This treatment time could be reduced by 42.75% in case a physician is supported by ED nurses or medical students. Thus on a daily basis ED physicians could save 269.84 minutes due to the changes in clinical pathways.

As the time needed to examine a patient varies in accordance to his or her cardinal symptom a diversified analysis of the treatment time for each cardinal symptom was performed as well. Most time could be saved while treating patients with headache. The time needed to treat patients with this cardinal symptom on average could be decreased by 9.19 minutes. Table 18 summarizes the possible reductions in the first examination by a physician for patients in general and diversified according to the most common cardinal symptoms.

The Mann-Whitney-U-test for unknown variances was performed in order to prove if there is a significant reduction in mean treatment times compared to the current system. The null hypothesis of this test (H_0 = there is no significant difference in mean values) can be rejected with a level of significance of α= 1% in case the test statistic (stated in the column 'U-test' in Table 18) is outside the 99% confidence interval of -2.576 and +2.576. As all test statistics are outside this interval it can be stated that the treatment time of patients for all cardinal symptoms could be decreased significantly.

	current state	Scenario B	deviation	U-test	savings per day
all cardinal symptoms	14.2642	8.1662	-42.75%	-23.8867	269.84
abdominal pain	14.1379	8.1245	-42.53%	-24.1521	64.82
thoracic pain	14.5804	8.2356	-43.52%	-24.5428	60.72
dyspnoea	15.5223	8.1309	-47.62%	-17.9504	32.30
headache	17.5549	8.3624	-52.36%	-7.3877	6.89
hypertension	13.2701	7.0572	-46.82%	-9.1595	7.46
palpitation	15.1032	10.1728	-32.64%	-6.1010	5.03
general malaise	15.5510	9.8541	-36.63%	-10.2714	13.90
other complaints	12.5288	7.2697	-41.98%	-22.2482	74.26

Table 18: Scenario B: Changes in time needed for the first examination

In a next step the effects of shifting certain treatment steps from physicians to other medical staff on waiting times and LOS have been analysed.

Table 19 summarizes the average waiting times and LOS as well as the mean CI and the upper and lower 5% quantile of the mean KPIs of Scenario B. All values are calculated based on a survey sample size of N= 1000 and denoted in minutes. In order to allow an easy comparison of the outcome in the current state and under Scenario B, the results of the analysis of the current state are stated in brackets behind the corresponding values.

In Scenario B, 90% of all patients stay at the ED between 20.83 and 214.01 minutes. Thereof patients are waiting between 4.49 and 184.90 minutes. Due to the changes in clinical pathways, the duration of the first examination by a physician could be reduced. In the current system 95% of all patients are examined by a physician within 25.27 minutes. As a physician is supported by other staff members in Scenario B, 95% of all patients could be treated within 15.43 minutes. Waiting and treatment times for discussing results stay almost constant.

	mean	**mean CI**	**5% quantile**	**95% quantile**
LOS	107.23 (119.18)	±4.08 (± 4.22)	20.83 (27.49)	214.01 (225.93)
total waiting time	81.81 (85.91)	±3.89 (± 3.94)	4.49 (4.66)	184.90 (189.75)
waiting time for first examination	25.20 (27.34)	±2.00 (± 1.90)	4.21 (4.18)	74.81 (74.72)
waiting time for discussing results	97.11 (98.38)	±2.26 (± 2.14)	46.41 (47.13)	163.26 (161.46)
duration of the first examination	8.17 (14.26)	±0.24 (± 0.37)	2.90 (5.67)	15.43 (25.27)
duration of discussing results	5.68 (5.73)	±0.26 (± 0.24)	0.86 (1.20)	14.22 (13.50)

Table 19: Scenario B: Summary of mean KPIs

The results from Table 19 lead to the conclusion, that the time a patient spends in the ED as well as the waiting time before the first examination by a physician can be decreased significantly due to the adaptations made in Scenario B. Therefore the significance of these changes in KPIs was analysed using the Mann-Whitney-U-test for unknown variances. The null hypothesis (H_0= there is no significant difference in mean values) can be rejected with a level of significance of $\alpha = 1\%$ in case the test statistic in the column 'U-test' lies outside the 99% confidence interval of -2.576 and + 2.576. In case the null hypothesis is rejected it can be assumed that with a probability of 99% there is a significant change in KPIs. In the scenario being studied, this would mean a significant reduction of waiting times.

Table 20 summarizes the main findings of a comparison between current waiting times and the model outcome of Scenario B. By decreasing the time needed for the first examination by a physician the waiting time for this process step could be reduced significantly. There is no significant change in the waiting time for discussing results as well as the total waiting time tough. LOS on the contrary could be reduced by 10% due to the decrease in waiting time for the first examination and the duration of the first examination by a physician.

	current state	Scenario B	U-test	deviation
LOS	119.1812	107.2341	-4.2214	-10.02%
total waiting time	85.9062	81.8099	-1.7402	-4.77%
waiting time for first examination by a physician	27.3397	25.2031	-3.4874	-7.81%
waiting time for discussing results	98.3785	97.1117	-1.3352	-1.29%

Table 20: Scenario B: Comparison of waiting times

In a next step it is analysed whether the decrease in LOS and waiting time for the first examination by a physician also affects the average number of patients in the system and resource utilization.

6.2.3 Average Number of Patients in the System and Resource Utilization

In Scenario B on average 3.39 patients are situated at the ED. Thereof 2.60 patients are in the waiting hall. During the peak hours between 16:00 and 20:00 the average number of patients in the system increases to 4.96, the average number of patients in the waiting hall to 3.68. Approximately 70% of all patients in the waiting hall are waiting for discussing results, during peak hours as well as over a 24-hour period. Only 30% have not yet been seen by a physician.

Table 21 summarizes the average numbers of patients in the current system and in Scenario B. This should provide an overview of how these KPIs change due to the adaptations to the system.

The average number of patients in the system could be reduced by 7.12% in case a physician is no longer obligated to write ECGs, take blood samples or prepare and delivers drugs. In addition the number of patients waiting for the first examination by a physician could be decreased by 3.75%. Due to the changes in clinical pathways and the reallocation of tasks at the ED the utilization of doctors and treatment rooms could be decreased by approximately one third.

average number of patients	current state (24-hours)	Scenario B (24-hours)	deviation
waiting for first examination by a physician	0.80	0.77	-3.75%
waiting for discussing results	1.86	1.83	-1.61%
in the system	3.65	3.39	-7.12%
in the waiting hall	2.67	2.60	-2.62%
waiting for administration	0.10	0.10	0.00%
ED efficiency	**current state (24-hours)**	**Scenario B (24-hours)**	**deviation**
utilization of doctors	31.10%	21.90%	-29.58%
utilization of treatment rooms	27.50%	18.20%	-33.82%
utilization administration clerk	35.20%	35.70%	+1.42%

Table 21: Scenario B: Comparison of average number of patients and ED efficiency

In order to evaluate how the system reacts to an increasing number of arriving patients, Table 22 summarizes how the average number of patients in the system and ED efficiency evolve during peak hours under Scenario B compared to the current system. During peak hours the average number of patients in the system and waiting for the first examination by a physician are lower compared to the current system. There are small reductions in the average number of patients waiting for discussing results and thus the average number of patients in the waiting hall is lower as well. The resource utilization of doctors and treatment rooms during peak hours is still about one third lower compared to the current system.

average number of patients	current state (peak hour)	Scenario B (peak hour)	deviation
waiting for first examination by a physician	1.10	1.03	-6.55%
waiting for discussing results	2.71	2.65	-2.14%
in the system	5.38	4.96	-7.86%
in the waiting hall	3.82	3.68	-3.66%
waiting for administration	0.25	0.25	-1.20%
ED efficiency	**current state (peak hour)**	**Scenario B (peak hour)**	**deviation**
utilization of doctors	45.75%	32.00%	-30.05%
utilization of treatment rooms	40.50%	26.70%	-34.07%
utilization administration clerk	53.10%	52.50%	-1.13%

Table 22: Scenario B: Comparison of peak hour performance

Similar to the formerly discussed scenarios, the average waiting times and LOS do not change significantly during peak hours. This can be proven statistically using the Mann-Whitney-U-test for unknown variances.

The null hypothesis (H_0= there is no significant difference in mean values) can be rejected with a level of significance of $\alpha = 1\%$ in case the test statistic in the column 'U-test' lies outside the 99% confidence interval of -2.576 and + 2.576. Table 23 summarizes how the mean KPIs evolve during peak hours. As none of the test statistics lie outside the 99% confidence interval it can be stated that waiting times and LOS in Scenario B do not increase significantly during peak hours. Thus it can be assumed that again the available resources are capable to meet the demand during peak hours.

	24-hour period	**peak hour**	**U-test**	**deviation**
LOS	107.2341	108.4108	-0.8467	+1.10%
total waiting time	81.8099	79.6870	-0.0296	-2.59%
waiting time for first examination by a physician	25.2031	22.3901	-2.0938	-11.16%
waiting time for discussing results	97.1117	99.9571	-1.9331	+2.93%

Table 23: Scenario B: Changes in mean KPIs during peak hours

Summarizing it can be stated that changing clinical pathways in the emergency outpatient clinic for internal medicine in a way that assures that the treatment steps ECG, taking a blood sample, and preparation and delivery of drugs are always performed by ED nurses or medical students would have a positive effect on ED performance.

The waiting time for the first examination by a physician could be reduced significantly and the time needed to perform the first examination by a physician could be decreased by more than 40%. Due to the reductions in waiting and treatment times a patient's LOS could be reduced by approximately 10%.

These improvements could be achieved without increasing the workload of physicians. On the contrary, ED doctors could save on average 269.84 minutes each day, in case other medical staff would support them during the first examination of a patient. In case these treatment steps are delivered simultaneously to other tasks of a physician or outside the treatment rooms for internal medicine, the utilization of treatment rooms could be decreased by approximately one third.

Although shifting certain tasks to other medical staff at the ED decreases the workload for ED doctors as well as patients' LOS, further research would be necessary in order to make a clear suggestion if this allocation would be manageable by the existing staff or if additional resources would be necessary. As in this simulation study the utilization of other staff members of the emergency outpatient clinic for internal medicine is not considered, it cannot be stated whether these resources would be capable to manage the additional tasks.

In addition the possibility that ED nurses or medical students would need a different amount of time to perform the upper mentioned treatment steps is not considered in Scenario B. Thus further examinations would be necessary in order to make a clear suggestion about changing clinical pathways in the emergency outpatient clinic for internal medicine.

6.3 Scenario C

The last scenario of the performed 'what-if' analysis deals with the effects of changing the number of available resources. It is analysed how an increase of treatment rooms and doctors would affect ED performance.

6.3.1 Setup of Scenario C

Currently two treatment rooms – denoted as treatment room 1 and treatment room 2 in Figure 1 one page 11 – are reserved for internal medicine in the emergency outpatient ward of Vienna General Hospital. In cases of high patient rush ED physicians may also deliver treatment in the corridor behind the treatment rooms or in the waiting hall. On workdays from 08:00 to 15:00 in general three ED doctors are on duty at the emergency outpatient clinic for internal medicine. On workdays from 15:00 to 08:00 and on weekends throughout the whole day two physicians are available at the outpatient ward.

As there is a restriction that treatment can only be delivered within treatment rooms in the simulation model, the number of available treatment rooms was set to two. The number of available doctors for treating patients within these treatment rooms was set to two as well. It is assumed that in case three physicians are on duty they rotate in order to guarantee that there always are two physicians available.

In Scenario C it is assumed that the number of available treatment rooms and doctors is increased by one and two. Thus the model outcome of a simulation including three treatment rooms and three doctors (Scenario C1), respectively four treatment rooms and four doctors (Scenario C2) was evaluated. This should provide a first impression if increasing the number of available resources would lead to improvements in ED performance. In addition the number of available resources was reduced by one in Scenario C3.

Besides the changes in resource levels none of the input variables and assumptions of the current system have been changed. ED physicians deliver all treatment steps on their own and they are not supported by ED nursed or medical students.

The effects of changing the resource levels on waiting times and LOS are outlined in the next subsection. Thereafter the changes in the number of patients in the system are discussed.

6.3.2 Waiting Times and Length of Stay

In Scenario C1 – including three available treatment rooms and doctors for treating patients at the emergency outpatient clinic for internal medicine – 90% of all patients leave the ED between 25.31 and 221.81 minutes. Compared to the current system – including two treatment rooms and two doctors – the 95% quantile could be decreased by 4.12 minutes. In Scenario C2, where four treatment rooms and doctors are available, 90% of all patients stay at the ED between 26.91 and 223.60 minutes. Compared to the current mean LOS this is a small improvement, compared to Scenario C1 the mean LOS even increases in Scenario C2.

The average total waiting time decreases in both Scenarios compared to the outcome of the current system, but again the output of Scenario C1 is better compared to the results of Scenario C2. The average total waiting times in Scenario C1 and Scenario C2 are very similar and do only deviate by approximately 0.05%. Nevertheless in Scenario C1 95% of all patients in total wait less than 184.35 minutes, whereas in Scenario C2 the same share of patients waits up to 186.77 minutes.

Although the average waiting time for the first examination by a physician could be decreased by 8.67% in Scenario C1, the 95% quantile for this KPI increases by 10.16 minutes. In Scenario C2 the 95% quantile even increases by 11.95 minutes, although the average waiting time decreases by 10.13%.

Referring to the waiting time for discussing results the 95% quantile increases in both scenarios of the ‘what-if’ analysis, whereas in Scenario C1 95% of all patients have to wait up to 162.84. In Scenario C2 95% of all patients wait less than 161.71 minutes until all their results are available. It is assumed that as this waiting time results from the time needed to perform blood tests in the central laboratory of Vienna General Hospital, an increasing number of available resources at the emergency outpatient ward would not affect the waiting time.

The mean KPIs of Scenario C1 and C2 are summarized in Table 24. Besides the average waiting times and LOS, the mean CI and the 5% quantile as well as the 95% quantile are stated. All values are calculated based on a sample size of N = 1000 and denoted in minutes. In addition the results of the analysis of the current state are mentioned in Table 24. This should allow an easier comparison of the model outcome under different scenarios.

Scenario C1	mean	mean CI	5% quantile	95% quantile
LOS	113.20	±4.29	25.31	221.81
total waiting time	82.85	±4.06	4.35	184.35
waiting time for first examination by a physician	24.97	±2.02	4.12	84.88
waiting time for discussing results	98.40	±2.22	47.84	162.84
Scenario C2	**mean**	**mean CI**	**5% quantile**	**95% quantile**
LOS	115.24	±4.11	26.91	223.60
total waiting time	83.26	±3.91	4.50	186.77
waiting time for first examination by a physician	24.57	±1.86	4.19	75.76
waiting time for discussing results	98.01	±2.21	46.39	161.71
current state	**mean**	**mean CI**	**5% quantile**	**95% quantile**
LOS	119.18	± 4.22	27.49	225.93
total waiting time	85.91	± 3.94	4.66	189.75
waiting time for first examination by a physician	27.34	± 1.90	4.18	74.72
waiting time for discussing results	98.38	± 2.14	47.13	161.46

Table 24: Scenario C: Summary of mean KPIs

As the simulation model is based on random number generators and the changes in the values stated in Table 24 are very small, in a next step it was analysed if mean KPIs differ significantly compared to the outcome of the current system or if these deviations only result from the random number generators.

In order to prove if there is a significant change in KPIs the Mann-Whitney-U-test for unknown variances was performed. The null hypothesis (H_0 = there is no significant difference in mean values) can be rejected with a level of significance of $\alpha = 1\%$ in case the test statistic lies outside the interval -2.576 and +2.576. In case the test statistic is outside the 99% confidence interval there is a significant change in KPIs, which could either be a reduction or increase in KPIs.

Table 25 summarizes the results of the hypothesis test. The test statistic is stated in the column 'U-test'. Besides a comparison of the current state and Scenario C1 and C2, the two Scenarios of the 'what-if' analysis have been compared to each other.

As it can be seen from Table 25 there is no significant change in LOS, total waiting time and waiting time for discussing results in case three or four doctors and treatment rooms are available. Nevertheless compared to the current system in both scenarios the waiting time for the first examination by a physician could be decreased significantly by 8.68% respectively 10.13%. Comparing the Scenario C1 and Scenario C2 there is no significant change in the waiting time for the first examination by a physician, tough.

	current state	**Scenario C1**	**U-test**	**deviation**
LOS	119.1812	113.2033	-2.2442	-5.02%
total waiting time	85.9062	82.8456	-1.6783	-3.56%
waiting time for first examination by a physician	27.3397	24.9678	-4.8830	-8.68%
waiting time for discussing results	98.3785	98.4047	-0.3163	+0.03%
	current state	**Scenario C2**	**U-test**	**deviation**
LOS	119.1812	115.2439	-1.2337	-3.30%
total waiting time	85.9062	83.2643	-1.1103	-3.08%
waiting time for first examination by a physician	27.3397	24.5698	-3.8518	-10.13%
waiting time for discussing results	98.3785	98.0068	-0.5056	-0.38%
	Scenario C1	**Scenario C2**	**U-test**	**deviation**
LOS	113.2033	115.2439	-1.0424	+1.80%
total waiting time	82.8456	83.2643	-0.5624	+0.51%
waiting time for first examination by a physician	24.9678	24.5698	-0.9866	-1.59%
waiting time for discussing results	98.4047	98.0068	-0.1944	-0.40%

Table 25 Scenario C: Comparison of waiting times

All in all increasing the number of available doctors and treatment rooms to three, respectively four, leads to a significant reduction in the average waiting time for discussing results. All other KPIs cannot be decreased significantly. This leads to the assumption that the available resources are capable to meet the current demand at the emergency outpatient clinic for internal medicine. The long LOS strongly depends on the delay time for blood test from the central laboratory and thus cannot be changed by increasing the number of resources at the emergency outpatient clinic.

6.3.3 Average Number of Patients in the System and Resource Utilization

In case there are three doctors and treatment rooms available at the emergency outpatient clinic for internal medicine on average 3.66 patients are situated at the ED. During peak hours this number increases by approximately 30% and reaches an average value of 5.29. Averagely there are 2.64 patients at the waiting hall, whereof 70% are waiting for discussing results and

30% have not yet been seen by a physician. This distribution is still valid during peak hours, where averagely 3.71 patients are situated in the waiting hall.

The outcome of Scenario C2 is very similar to the outcome of Scenario C1. On average there are 3.67 patients at the ED considering a 24-hour period. During peak hours this number increases by approximately 30%. On average there are 2.65 patients in the waiting hall over a 24-hour period and 3.61 patients during peak hours. Thereof 70% are waiting for discussing test results and 30% are waiting for the first examination by a physician.

Table 26 summarizes the average number of patients in the system as well as ED efficiency of the current state, Scenario C1 and Scenario C2. The percentage changes compared to the current system are stated in brackets behind the corresponding values.

24-hour period			
average number of patients	**current state**	**Scenario C1**	**Scenario C2**
waiting for first examination by a physician	0.80	0.79 (-1.38%)	0.78 (-2.88%)
waiting for discussing results	1.86	1.85 (-0.38%)	1.87 (+0.48%)
in the system	3.65	3.66 (+0.22%)	3.67 (+0.41%)
in the waiting hall	2.67	2.64 (-1.05%)	2.65 (-0.90%)
waiting for administration	0.10	0.12 (+16.50%)	0.17 (+61.17%)
ED efficiency	**current state**	**Scenario C1**	**Scenario C2**
utilization of doctors	31.10%	21.00% (-32.48%)	15.90% (-48.87%)
utilization of treatment rooms	27.50%	18.50% (-32.73%)	14.10% (-48.73%)
utilization administration clerk	35.20%	36.40% (+3.41%)	36.40% (+3.41%)
peak hours			
average number of patients	**current state**	**Scenario C1**	**Scenario C2**
waiting for first examination by a physician	1.10	1.02 (-7.45%)	0.97 (-11.55%)
waiting for discussing results	2.71	2.69 (-0.63%)	2.64 (-2.58%)
in the system	5.38	5.29 (-1.71%)	5.16 (-4.18%)
in the waiting hall	3.82	3.71 (-2.85%)	3.61 (-5.42%)
waiting for administration	0.25	0.28 (+9.45%)	0.25 (-3.54%)
ED efficiency	**current state**	**Scenario C1**	**Scenario C2**
utilization of doctors	45.75%	30.30% (-33.77%)	22.80% (-50.16%)
utilization of treatment rooms	40.50%	26.80% (-33.83%)	20.10% (-50.37%)
utilization of administration clerk	53.10%	52.50% (-1.13%)	52.40% (-1.32%)

Table 26: Scenario C: Comparison of average number of patients and ED efficiency

Summarizing it can be stated, that the average number of patients in the system could not be decreased significantly due to an increasing number of available resources. Resource utilization, on the contrary, is very sensitive to these adaptations. The utilization of the resources doctor and treatment room could be decreased by one third in case the number of these resources is set to three. In case four treatment rooms and doctors are available the utilization could even be decreased by approximately 50%. This is valid considering a 24-hour period as well as only the peak hour period between 16:00 and 20:00.

Waiting times and LOS during peak hours have been analysed as well. In order to show if there is a significant change in KPIs during peak hours the Mann-Whitney-U-test for unknown variances was performed. The null hypothesis (H_0 = there is no significant difference in mean values) can be rejected with a level of significance of $\alpha = 1\%$ in case the test statistic lies outside the interval -2.576 and +2.576.

The results of this hypothesis test are summarized in Table 27. It can be stated that in both 'what-if' scenarios there is no significant increase in waiting times and LOS during peak hours. Thus the resources are capable to meet the demand during peak hours as well.

Scenario C1	**24-hour period**	**peak hour**	**U-test**	**deviation**
LOS	113.2033	117.4293	-2.2209	+3.60%
total waiting time	82.8456	83.6127	-1.2471	+0.92%
waiting time for first examination by a physician	24.9678	21.7350	-1.9567	-14.87%
waiting time for discussing results	98.4047	98.0148	-0.2703	-0.40%
Scenario C2	**24-hour period**	**peak hour**	**U-test**	**deviation**
LOS	115.2439	109.8751	-1.4774	-4.89%
total waiting time	83.2643	76.8161	-1.8470	-8.39%
waiting time for first examination by a physician	24.5698	20.4862	-0.4475	-19.93%
waiting time for discussing results	98.0068	96.0785	-1.5511	-2.01%

Table 27: Scenario C: Changes in mean KPIs during peak hours

As a conclusion it can be stated that increasing the number of available treatment rooms and doctors to three, respectively to four, could significantly reduce the waiting time for the first examination by a physician. All other KPIs do not change significantly due to the increasing number of available resources.

As the average number of patients in the system as well as LOS stayed nearly unchanged in Scenario C1 and C2 it is assumed that the current resources are capable to meet the demand at the emergency outpatient clinic for internal medicine. Increasing the number of resources would not be efficient as in Scenario C1 / C2 the resource utilization of doctors decreases to 21.00% / 15.90%, whereas treatment rooms are only utilized to 18.50% / 14.10%. Therefore it is recommended to stick to the current resource level.

Nevertheless it has to be considered that one characteristic of the health care sector is the uncertainty of demand. Therefore in cases of unpredictable events, like a significant increase in the number of arriving patients, more available resources could be needed. An additional treatment room could also be needed in case one treatment room is occupied for a long period of time due to an elaborate treatment of a patient or due to a breakdown of medical instruments in the treatment room.

Thus in a last step of Scenario C, the effects of decreasing the number of resources has been evaluated in brief. It was assumed that one treatment room is closed and as a result from now on only one treatment room is available (Scenario C3). As treatment is only possible within a treatment room, the number of the resource doctor was set in accordance to the number of available treatment rooms.

In this scenario waiting times and LOS increase significantly. This was proven using the Mann-Whitney-U-test for unknown variances. The null hypothesis (H_0 = there is no significant difference in mean values) can be rejected with a level of significance of $\alpha = 1\%$ in case the test statistic lies outside the interval -2.576 and +2.576. The results of a comparison of the current system and a scenario where only one treatment room and one doctor are available are summarized in Table 28.

As in all cases the test statistic for the Mann-Whitney-U-test lies outside the 99% confidence interval it can be stated that LOS as well as all waiting times increase significantly. The mean LOS increases by 28.09%, the total waiting time increases by 41.31%. While the average waiting time for discussing results increases by 17.93%, the average waiting time for the first examination by a physician almost doubles.

	current state	Scenario C3	U-test	deviation
LOS	119.1812	152.6587	-8.3450	+28.09%
total waiting time	85.9062	121.3968	-9.6368	+41.31%
waiting time for first examination by a physician	27.3397	54.1995	-16.6596	+98.24%
waiting time for discussing results	98.3785	116.0143	-9.9122	+17.93%

Table 28: Scenario C3: Comparison of waiting times

During peak hours the mean KPIs would once more increase significantly. The results of the peak hour analysis are stated in Table 29. Due to a utilization of the resource doctor of 89% and the resource treatment room of 78.90% during peak hours, it is assumed that the resources are overallocated and thus waiting times and LOS increase significantly.

	24-hour period	peak hour	U-test	deviation
LOS	152.6587	186.7067	-7.6275	+18.24%
total waiting time	121.3968	153.7399	-7.5888	+21.04%
waiting time for first examination by a physician	54.1995	78.2207	-9.7180	+30.71%
waiting time for discussing results	116.0143	122.7890	-4.3453	+5.52%

Table 29: Scenario C3: Comparison of average number of patients and ED efficiency

Analysing a scenario where only one treatment room and one doctor are available it can be shown that at least two treatment rooms and doctors are needed to manage the treatment of all arriving patients at the emergency outpatient clinic for internal medicine. In case fewer resources are available waiting times and LOS would increase significantly.

Thus it can be recommended, not to decrease the number of available resources, as otherwise ED performance would significantly decline. In order to make a clear statement about the efficiency of increasing the number of treatment rooms and doctors at the ED, on the contrary, further research would be necessary.

7 Conclusion

This master thesis deals with a discrete event simulation of the emergency outpatient clinic for internal medicine in Vienna General Hospital. After creating a conceptual model, a computerized simulation model was conducted. The main aim was to illustrate the general patient flow in the ED and analyse how a patient's time is spent. Similar to other simulation studies in this field of research patients' throughput time as well as ED efficiency were the main points of interest.

By simulating the current state at the ED it was shown that approximately 70% of a patient's time at the ED is waiting time. The waiting time for discussing results of diagnostic testing, e.g. blood tests – which are performed in the central laboratory of Vienna General Hospital – takes the biggest share of total waiting time. In addition it was proved that the treatment time of a patient depends on his or her cardinal symptom, as different treatments are delivered to patients with different complaints. A detailed analysis of a whole day at the ED and the peak hours between 16:00 and 20:00 lead to the assumption that the available resources are capable to meet the demand of a normal day at the emergency outpatient clinic for internal medicine.

In addition to an analysis of the current state at the ED, a systematic increase of patients arriving at the emergency outpatient clinic for internal medicine was performed. The bottleneck analysis showed that the patient flow would first be hindered at the administration at the front desk. An increase of patients by 20% would already lead to an increase in waiting times for the administration by 12.50%. Waiting times for the first examination by a physician would not increase significantly until an increase in arriving patients by 40%. Patients LOS would not increase significantly until an increase by 70%.

Thus, in Scenario A of the performed 'what-if' analysis it was attempted to remove this bottleneck. By changing the general process flow at the front desk, the average total waiting times could be reduced by 24.00% and the average waiting time for the first examination by a physician could be reduced by more than two thirds. These improvements could be achieved only by changing the general process flow at the ED and without increasing the workload for physicians.

In Scenario B of the 'what-if' analysis the clinical pathways at the ED were changed and its effects were analysed. It was assumed that ED nurses or medical students always support physicians during the first examination of a patient. This would reduce the workload of a physician by 269.84 minutes each day. In addition patients' LOS could be reduced by approximately 10%.

Scenario C experimented with the number of available resources in the emergency outpatient clinic for internal medicine. Increasing the number of available treatment rooms and doctors by one, respectively two, the average waiting time for the first examination by a physician could be decreased by 8.68%, respectively 10.13%. All other KPIs did not change significantly due to the increasing number of resources. Besides a small improvement in ED performance the adaptations made in Scenario C lead to a strong decrease in resource utilization. Reducing the number of available resources, on the contrary, would lead to an increase in patients' LOS by approximately 30% and the waiting time for the first examination by a physician would almost double. Waiting times would increase significantly, as a single doctor would not be capable to treat all arriving patients.

Summarizing it shall be mentioned that the created simulation model showed that the available resources at the emergency outpatient clinic for internal medicine are able to manage the current patient demand. Nevertheless by changing the process flow at the front desk or by adding additional staff, which supports ED doctors during the examination of a patient, patients' LOS could be reduced significantly.

In order to make clear suggestions if changing the process flow at the ED would be efficient further examinations would be necessary, though. In the performed 'what-if' analysis the cost perspective of the adaptations to the system was not considered. Regarding Scenario A the financial expenditures of changing the process flow at the ED have to be considered in order to evaluate if changing the administration at the front desk would be efficient. Although a reduction in patients' LOS could be achieved in Scenario B, the effects on other staff members at the ED have to be considered before changing clinical pathways at the ED. In Scenario C the probability of the number of arriving patients at the ED increasing significantly should be considered before rejecting the idea of increasing the number of available treatment rooms and doctors.

All in all, the simulation model provides a good overview of current ED performance and the effects of changing special input factors or the process flow. Before implementing the considered changes in the system, further examinations would be necessary, tough.

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Abstract

Playing the role of a ‘gate-keeper‘ in an emergency department medical aid is delivered twenty-four-seven and it is decided whether a patient has to be admitted to a hospital or not. Due to the increasing number of patients visiting emergency departments during the last decades, overcrowded waiting halls and long waiting times are very common problems in hospitals.

As there are various reasons for long waiting times in emergency departments, hospital managers have to gain better understanding of the general patient flow in their facilities in order to investigate in a way that reduces waiting times and increases efficiency. The main aim of this master thesis was to build a discrete event simulation model of the emergency outpatient clinic for internal medicine of Vienna General Hospital. By analysing the current patient flow, patients’ throughput time and resource utilization have been evaluated. In addition bottlenecks in the process flow have been analysed and by changing the general process flow it was attempted to reduce waiting times and increase efficiency in the emergency outpatient clinic.

Deutsche Zusammenfassung

Notaufnahmen bieten rund um die Uhr medizinische Versorgung und spielen eine wesentliche Rolle in der Entscheidung ob ein Patient stationär aufgenommen werden muss oder nicht. Aufgrund der steigenden Anzahl an Ambulanzbesuchen sind überfüllte Wartesäle und lange Wartezeiten häufig auftretende Probleme in Krankenhäusern.

Die Gründe, die zu langen Wartzeiten in Notaufnahmen führen können, sind vielfältig. Deshalb ist es wichtig, dass die Abläufe in diesen Abteilungen genau verstanden werden. Nur so können Engpässe im Prozessablauf aufgedeckt und beseitigt werden. Das Ziel dieser Masterarbeit war es, eine Discrete Event Simulation der Notfallambulanz für interne Medizin des Allgemeinen Krankenhauses der Stadt Wien zu erstellen. Dieses Modell bietet die Möglichkeit Aussagen über Durchlaufzeiten und Ressourcenauslastung zu treffen. Außerdem konnten durch das Simulationsmodell Kapazitätsengpässe aufgezeigt und mögliche Änderungen der Prozessabläufe erprobt werden.

Curriculum Vitae

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Appendix – Detailed Results of the Bottleneck Analysis

N = 1000 99% CI [-2.576;+2.576]	**0%**	**+ 10%**	**+ 20%**	**+ 30%**	**+ 40%**	**+ 50%**	**+ 60%**	**+ 70%**	**+ 80%**	**+ 90%**	**+ 100%**
LOS	119.18	116.97	118.07	117.96	123.64	126.24	122.03	127.88	127.28	139.70	146.65
U-test		-0.7587	-0.2693	-0.0064	-1.4799	-2.2845	-1.2588	-3.2763	-2.9422	-6.2483	-8.4163
deviation		-1.86%	-0.93%	-1.02%	+3.74%	+5.92%	+2.39%	+7.30%	+6.80%	+17.22%	+23.05%
total WT	85.91	84.72	85.04	85.61	85.86	87.51	85.07	89.38	87.95	92.82	96.68
U-test		-0.5994	-0.4692	-0.0163	-0.5084	-1.1480	-0.4225	-2.1952	-1.5049	-3.4869	-4.6892
deviation		-1.38%	-1.00%	-0.34%	-0.05%	+1.87%	-0.97%	+4.04%	+2.37%	+8.05%	+12.54%
WT for first examination	27.34	26.17	25.81	26.62	27.90	28.16	27.40	28.40	28.98	31.09	33.57
U-test		-0.7497	-0.3732	-0.5886	-3.6682	-3.6364	-4.3469	-5.6445	-5.7878	-8.9883	-11.7454
deviation		-4.26%	-5.59%	-2.62%	+2.05%	+2.98%	+0.22%	+3.87%	+6.00%	+13.72%	+22.80%
WT for discussing results	98.38	98.80	101.36	99.58	99.59	98.87	100.20	101.53	101.99	102.96	105.60
U-test		-0.1539	-0.1902	-0.7106	-0.7114	-0.0664	-0.9062	-1.9231	-1.8900	-2.6864	-4.3889
deviation		+0.43%	+3.03%	+1.22%	+1.24%	+0.50%	+1.85%	+3.21%	+3.68%	+4.65%	+7.34%
WT for administration	13.55	12.82	15.24	14.14	18.56	19.35	17.80	19.25	20.35	27.87	30.93
U-test		-1.0172	-3.5038	-2.6231	-5.7334	-6.8948	-7.1378	-8.8273	-9.3122	-12.9514	-16.0390
deviation		-5.42%	+12.50%	+4.37%	+36.97%	+42.85%	+31.38%	+42.10%	+50.18%	+105.68%	+128.27%

Table 30: Bottleneck analysis current state

N = 1000 99% CI [-2.576;+2.576]	**0%**	**+ 10%**	**+ 20%**	**+ 30%**	**+ 40%**	**+ 50%**	**+ 60%**	**+ 70%**	**+ 80%**	**+ 90%**	**+ 100%**
LOS	96.12	96.66	97.94	95.33	99.45	98.65	100.50	102.37	103.22	109.38	113.04
U-test		-0.4582	-0.7269	-0.3038	-1.6578	-1.3917	-1.7642	-2.6796	-2.6749	-4.9293	-6.2349
deviation		+0.56%	+1.90%	-0.82%	+3.47%	+2.64%	+4.56%	+6.50%	+7.39%	+13.79%	+17.60%
total WT	65.28	65.62	65.88	63.69	66.35	64.96	67.04	68.41	68.25	71.86	75.47
U-test		-0.0344	-0.0988	-0.9444	-0.5011	-0.4035	-0.8940	-1.8945	-1.6748	-2.9682	-4.5261
deviation		+0.52%	+0.92%	-2.45%	+1.63%	-0.49%	+2.69%	+4.79%	+4.55%	+10.07%	+15.60%
WT for first examination	6.04	6.04	6.34	6.17	6.28	7.78	7.82	7.78	9.30	11.71	13.60
U-test		-0.3602	-1.7899	-0.5243	-1.9750	-5.5585	-4.8357	-7.2306	-7.4931	-9.6902	-13.7107
deviation		+0.03%	+5.03%	+2.12%	+4.07%	+28.88%	+29.52%	+28.88%	+54.05%	+93.97%	+125.31%
WT for discussing results	99.26	98.40	98.71	98.41	99.88	99.62	100.32	101.62	99.16	101.61	101.01
U-test		-1.0063	-0.5182	-0.1352	-1.1824	-1.3306	-1.5859	-2.4755	-1.1654	-2.7007	-1.9384
deviation		-0.87%	-0.56%	-0.86%	+0.62%	+0.36%	+1.06%	+2.37%	-0.11%	+2.37%	+1.76%
WT for administration	11.67	12.07	12.99	12.86	14.32	14.79	14.42	15.23	15.89	18.82	18.44
U-test		-1.8804	-2.5173	-2.5517	-5.6005	-6.0933	-5.2210	-7.5814	-6.7892	-10.1312	-11.0747
deviation		+3.38%	+11.28%	+10.20%	+22.72%	+26.70%	+23.59%	+30.48%	+36.13%	+61.23%	+58.04%

Table 31: Bottleneck analysis Scenario A