Analysis and prediction of effects of the Manchester Triage System on patient waiting times in an emergency department by means of agent-based simulation

Analyse und Vorhersage der Auswirkungen des Manchester Triage Systems auf Wartezeiten der Patienten in einer Notfallaufnahme durch agentenbasierte Simulation

Michael Schaaf[1,2]
Gert Funkat[1,2]
Oksana Kasch[2]
Christoph Josten[2]
Alfred Winter[1]

1 Institute for Medical Informatics, Statistics and Epidemiology (IMISE), Leipzig, Germany

2 University Hospital Leipzig AöR (UKL), Leipzig, Germany

Abstract

A simulation of complex clinical processes is a challenging task and suitable methods need to be found which can capture the influence of relevant factors and their relationships. The Manchester triage system (MTS) is widely used in German emergency departments (ED), however the impact on patient waiting times remain difficult to predict. The purpose of this work is the assessment of MTS particularly with regard to the waiting times of different degrees of severity. The methodology of agent based simulation was found suitable for the ED domain and the agent based simulation tool SeSAm was chosen due to its intuitive user interface and easy adaption of the simulation models. Altogether four agent classes could be implemented based on the information derived from a process model. The model permits a dynamic simulation of the ED processes and a reliable assessment of patient waiting times. In addition, the implementation of a triage nurse allowed the simulation of the triage process and a direct comparison to the current state without a standardized triage procedure. Essential influencing factors (e.g. number of patients, manning level) were implemented and their effects on the ED processes and patient waiting times assessed. The simulation runs delivered correct results based on the underlying process model and the collected statistical data. The process flow and the waiting times of an ED could be mapped exactly. In all simulation runs the waiting times of high triage levels (MTS-levels 1 and 2) could be reduced. Especially patients of MTS-level 2 in the waiting area of the ED benefit significantly from the implementation of a standardized triage procedure and the associated permanent monitoring.

Zusammenfassung

Die Simulation komplexer klinischer Prozesse ist eine herausfordernde Aufgabe und erfordert die Identifikation geeigneter Methoden und Werkzeuge, die in der Lage sind den Einfluss relevanter Faktoren abzubilden. In deutschen Notfallaufnahmen (NFA) ist das Manchester Triage System (MTS) zur Ersteinschätzung von Notfallpatienten weit verbreitet, jedoch lässt sich dessen Einfluss auf Patientenwartezeiten nur schwer vorhersagen. Ziel der vorliegenden Arbeit ist die Bewertung von MTS hinsichtlich des Faktors Wartezeit von Patienten unterschiedlicher Behandlungsdringlichkeitsstufen. Basierend auf einem abgeleiteten Prozessmodell der NFA konnten insgesamt vier Agentenklassen in der agentenbasierten Simulations- und Auswertungsumgebung SeSAm implementiert werden. Das Modell erlaubt die Simulation dynamischer Prozesse einer NFA und die Bewertung der Patientenwartezeiten unterschiedlicher Patiententypen. Die zusätzliche Implementierung einer Triage-Plfegekraft ermöglicht die Simulation der Ersteinschätzung von

Notfallpatienten und den direkten Vergleich zum aktuellen Zustand ohne Ersteinschätzung. Im Simulationsmodell werden wichtige Einflussfaktoren (z.B.: Patientenauslastung, Personalstärke) berücksichtigt und deren Einfluss auf die NFA-Prozesse und die Patientenwartezeiten bewertet. Die Simulationsläufe generieren, basierend auf dem zugrundeliegenden Prozessmodell und den verwendeten statistischen Daten, korrekte Ergebnisse. Der Prozessablauf und die Patientenwartezeiten einer NFA konnten präzise abgebildet werden. In allen Simulationsläufen konnten die Wartezeiten von Patienten mit hoher Behandlungspriorität (MTS-Stufen 1 und 2) reduziert werden. Insbesondere Patienten mit MTS-Stufe 2 profitierten in den Simulationsläufen erheblich von der Integration eines standardisierten Verfahrens zur Ersteinschätzung in den Prozessablauf und der damit verbundenen kontinuierlichen Überwachung von Notfallpatienten.

1 Introduction

Every year more than 21 million emergency patients are treated in German emergency departments (ED). The number of patients increases nationwide every year between 5–10% and will continue to rise sharply [1], [2]. This is a result of many factors, for example the demographic development and the disappearance of general medical practices in rural areas. Not only will the number of patients in a poor state of health increase, the number of those in a comparatively good health condition will rise, too [1]. This can be attributed to deficits in the process of preclinical patient guidance and various factors like daytime, day of the week and season [2]. However, only a small fraction of the patients are in life-threatening situations and must be identified precisely within a few minutes [3]. As a consequence, available resources face the risk of being temporarily overloaded and thus patients may be endangered. This indicates the importance of determining the treatment priority in a quick, reliable and comprehensible way. The way of assessment of patients in the waiting area of an ED mainly depends on the personal qualifications and experience of the admitting staff. Without standardization the quality of the assessment of emergencies varies and a considerable risk of overlooking life-threatening situations exists. Another problem is that patients in the waiting area of the ED who are in a very serious condition are unsupervised. Sudden condition changes of unattended patients could pass unnoticed. With the help of a standardized procedure for assessing and monitoring emergencies, taken decisions about the order of treatment are documented and a proper legal compliance is ensured [4]. Such a procedure is called triage which is a generic term for different procedures assessing the patient's severity of injury within a short time frame after arriving at the ED. For every patient admitted to the ED a professionally experienced triage nurse assigns the reported complaints in each case to a defined algorithm and determines the treatment priority using fixed rules that take account of vital signs. The method of triage does not aim at reducing waiting times of an ED, but at ensuring that valuable time is not wasted to the disadvantage of patients in seriously bad conditions [5]. The most important triage methods used internationally in ED are the Canadian Triage and Acuity Scale (CTAS), the Australasian Triage Scale (ATS), the Manchester Triage System (MTS) and the Emergency Severity Index (ESI) [6]. The number of emergency care departments in Germany using MTS developed in England rises year after year. MTS and ESI are already successfully applied at German EDs. Both belong to the internationally recommended five level triage systems, which are considered to be valid and reliable [7], [8], [9], [10], [11]. Currently more than 150 hospitals in Germany use MTS and additional 50 hospitals plan the setting up, implementation and operation of MTS [12]. However, the precise effects on factors like patient's waiting time by introducing a standardized triage procedure are largely unknown. By using a simulation model one would be capable of understanding the effects of process changes before implementing a triage procedure. Problems uncovered during a simulation run can be avoided in real-world operation. It can help to compare the current processes of an ED with the hypothetical situation that would be encountered if there were a triage procedure. The results of the simulation run can provide critical information for the investigation of possible causes for delays in patient care. Since patients in a very serious condition have to be treated as fast as possible, the main objective of the simulation runs should be the comparison of waiting times with and without the use of a standardized triage procedure as for example MTS.

Developing a simulation model needs to capture all relevant activities of an ED and to map them to a dynamic process model understanding the logical process order and staff involved.

This paper therefore deals with the following questions:

1. How can the complex processes of an ED be mapped to a structured simulation model?
2. How would the implementation of MTS affect the patient waiting times?

2 Materials and methods

A detailed model of the complex processes of an ED is the prerequisite for the simulation and assessment of patients' waiting times after the introduction of MTS. The

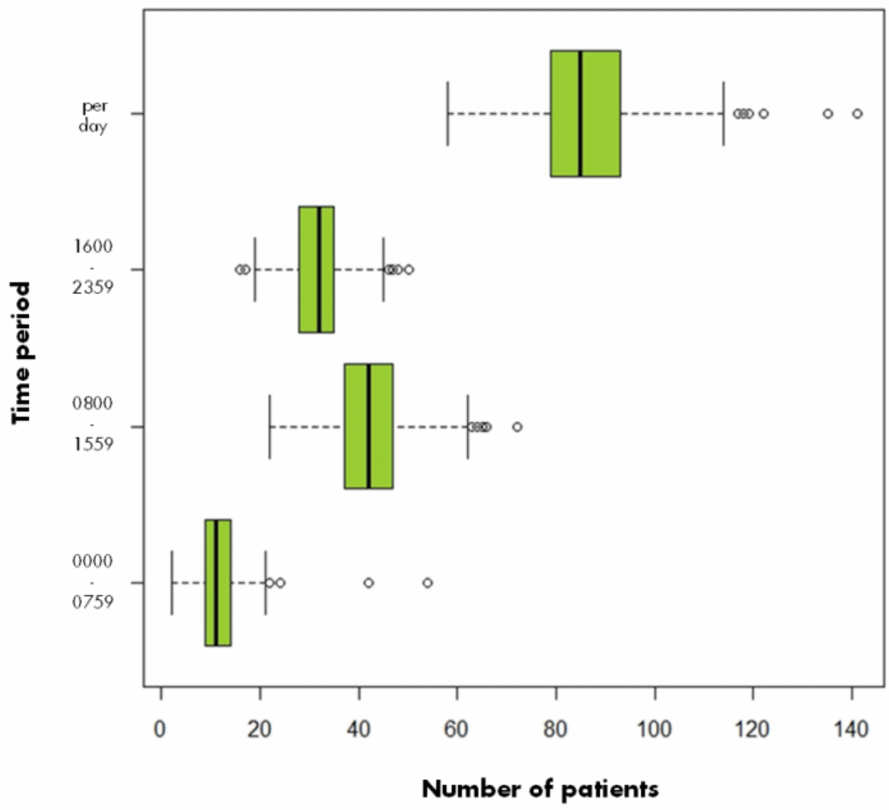


Figure 1: Box-Whisker-plot of the number of patients at certain periods of time the day (41,143 patients, 477 days)

model must be supplemented by statistical data, such as the distribution of emergencies over time or the frequency of certain symptoms. Finally, an appropriate simulation tool has to be chosen and the developed process model needs to be integrated. Once these steps are taken, the specific simulation runs for the analysis can be performed and analyzed.

2.1 Construction of the process model

Particularly with regard to the mapping of processes and workflows the complex process structures need to be kept in mind. A balance must be achieved between mapping the complex process structures on the one hand and the further use of this model by implementation of a simulation on the other. Curtis et al. mention general requirements of description languages, which need to be rated depending on the system to be modeled [13]. Key properties are user-friendliness, clearness, accuracy, level of awareness and tool support [14]. The process description languages BPMN (Business Process Model and Notation) and EPC (Event-driven Process Chain) are able to easily grasp and represent the process dynamics. BPMN enables a very complex modeling depth (e.g. event controlling clarifies decision-making) and allows a more detailed representation of data flows than EPC [15]. The benefit of EPCs is modeling in an intuitive and easy way [16]. The resulting models are characterized by a high degree of intelligibility and interpretability. Therefore the choice fell on EPCs. The processes of the ED at Universitätsklinikum Leipzig were analyzed over a period of several weeks and a process model was constructed [17]. The resulting process model comprises 12 process categories including more than 100 basic processes focusing on the nursing processes of the ED at UKL.

2.2 Collection of statistical data

In order to simulate the performed processes of the ED, statistical data of patients, physicians and nursing staff is required. The data necessary for the calculation and simulation originate from the emergency department of Universitätsklinikum Leipzig. A large proportion of the data was derived from the database of the patient management system based on SAP-software, while the rest of the required data was obtained by observation over a sufficiently extended period of time. The most important attributes are the distribution of patient flows, the distribution of their MTS-level and the nursing procedures needing to be performed. Based on this basic data one may randomly simulate different kinds of emergencies at different times in order to analyze the varying utilization of an ED.

Distribution of patient flows

For the correct implementation and simulation of the processes the number and distribution of patients that are admitted within a specific time period need to be determined. As shown in Figure 1, the arrival times of 41,143 patients on 477 days were evaluated [18]. It can be seen easily that the three equidistant time periods

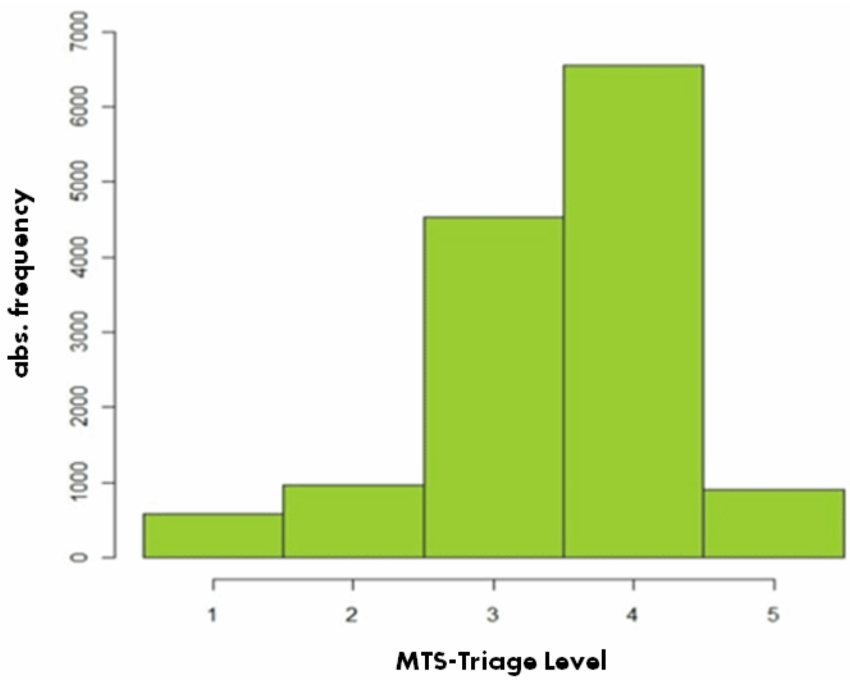


Figure 2: Distribution of MTS-levels during a pilot project in 2009. The data set comprises the MTS-levels of 13,541 emergency patients.

have varying patient flows at different times. In the night period from 00:00 a.m. to 07:59 a.m. a comparatively lower admission rate could be expected than in the other time periods. The reasons for statistical outliers (empty circles) are difficult to determine. On the one hand public holidays can be of significance, on the other hand factors like the season, bigger events or mass casualty incidents could cause them.

Distribution of urgency levels

In the period from March to October 2009 a triage test run was performed where the majority of all incoming patients were assessed [18]. Unfortunately, no additional nursing staff was available for the triage process making it impossible to sustain in times of stress. The data set shown in Figure 2 comprises the triage-levels of 13,541 patients and is used as an estimator for the random variable of the simulation model. Validated studies of comparable EDs in Germany provide similar results. It is especially noteworthy that only approximately 15% of all patients belonged to the most critical levels one and two.

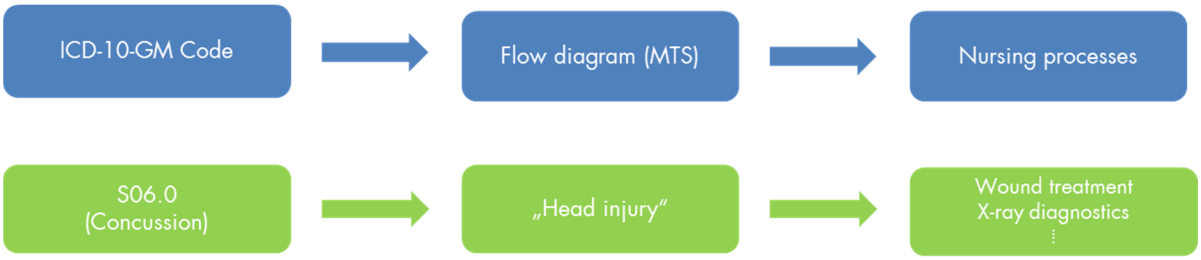
Distribution of physical impairments and derived processes

The simulation model requires information about which physical impairments initiate which specific nursing services. Although the frequency of the Top-20 ICD-10 codes of the past years is a known fact [19], no according dataset of the frequency of the MTS-symptom classes was available. Therefore a mapping from the ICD-10 codes to the according MTS-symptom class was necessary, as the MTS is not based on diagnoses but on symptoms (Figure 3).

2.3 Construction of the simulation model

Modeling and simulation of complex systems using agent-based simulation is a powerful, yet in health care rarely used further development of discrete event simulation [20]. An agent is *"... a computer system that is situated in some environment, and that is capable of autonomous action in this environment in order to meet its design objectives."* [21]. These agents perceive information on their environment by means of sensors. They recognize and purse their scope of actions, respond to changes of their environment and adapt their implemented behavior. It is important to understand that there is no determined script for the agent behavior. The agent interprets the meaning of an event and selects a suitable reaction. Multi-agent systems involve several similar or diverse specialized interacting agents that solve a problem collectively.

From currently over 60 available tools the agent-based simulation tool SeSAm (Shell for Simulated Agent Systems) was chosen precisely due the possibility to implement and simulate complex models in an uncomplicated way [22]. SeSAm provides a generic environment capable of constructing complex models, which include dynamic independencies or emergent behavior. SeSAm uses the main entities agents, resources and the world. The most important part when modeling the agent behavior is the Agent Reasoning Engine (ARE) and the according variables. The engine is based on the UML notation and uses activity diagrams inspired by UML activity diagrams, as shown in Figure 4. If an agent is in a certain activity state it will perform the state's actions depending on specific rules.



ICD-10-GM	Description	MTS-Class	Derived processes	Frequency
S06.0	Concussion	Head injury	Wound treatment, x-ray diagnostics, …	262
I63.4	Cerebral Infarction	Headache	PDMS-Monitoring, laboritory examination,…	95
K35.9	Acute appendicitis, other and unspecified	Abominal pain in adults	PDMS-Monitoring, laboritory examination, administering perfusion, ECG,…	59
G40.2	Epilepsy	Fits	PDMS-Monitoring, laboritory examination, administering perfusion, ECG,…	55
J18.0	Bronchopneumonia, unspecified	Shortness of breath in adults	PDMS-Monitoring, laboritory examination, administering perfusion, ECG,…	44

Figure 3: Extract from the recorded data of the ICD-10-codes and the derived MTS-classes

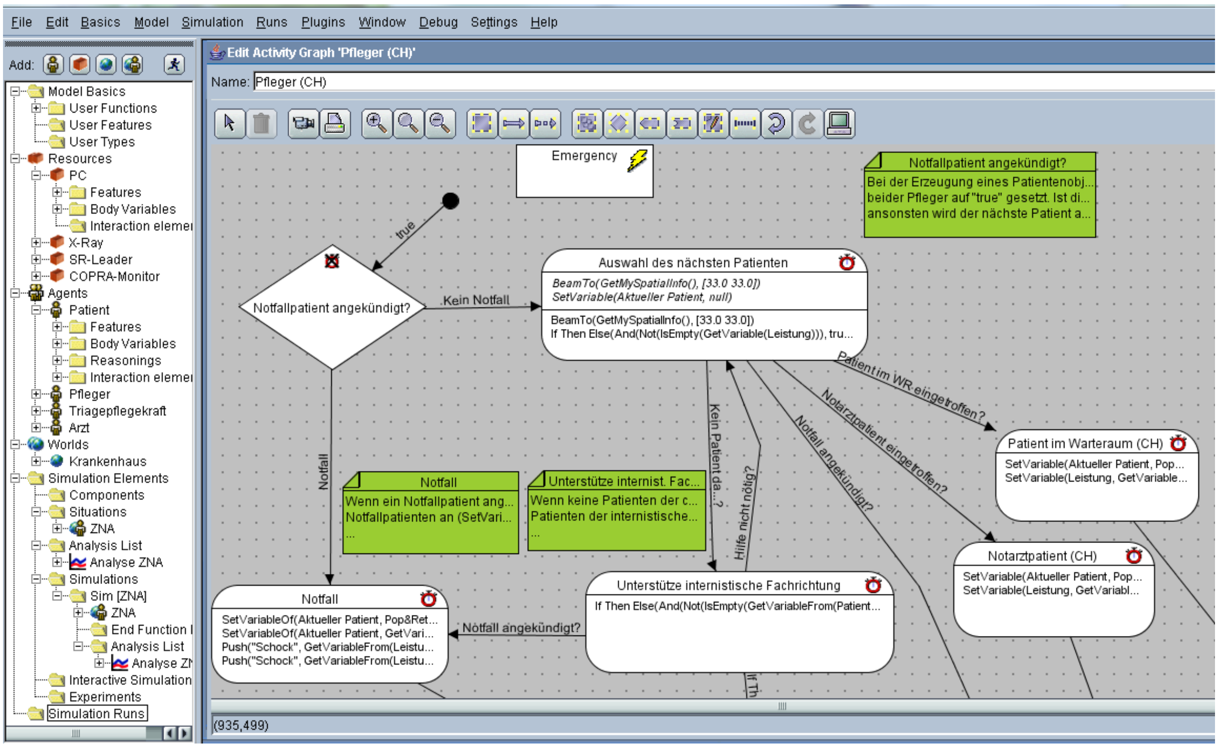


Figure 4: Agent Reasoning Engine (ARE). The specification of each agent class is realized using visual programming in a high-level, declarative visual programming language.

The agents at a glance

The simulation model must represent the real systems exactly enough in order to be allowed to draw conclusions from the simulation runs. This was done by implementing four agent classes. The following is a simplified semiformal description of the agents' behavior.

The world agent

During the simulation the world agent is responsible for the following main tasks:

- Generation of all agent objects of the agents' classes
- Management of personnel and functional areas
- Realization of a time model (day and week cycles)

The steps shown in Figure 5 are performed each run:

1. Creation of all simulation objects. This step includes instantiating the nursing staff and providing all graphical features (background, images).
2. The variables will be assigned. Especially the total number of patients of each phase is randomly selected (based on the collected statistical data → Section 2.2). This step is repeated after every phase.

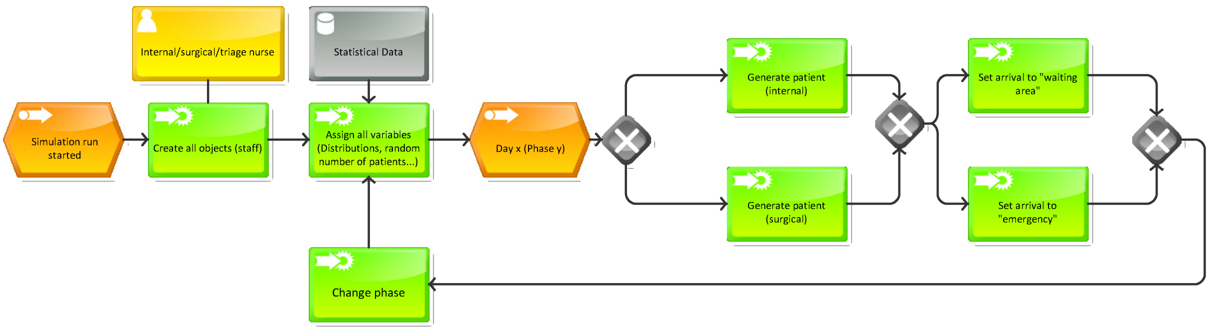


Figure 5: Simplified outline of the behavior of the agent class "world" (EPC)

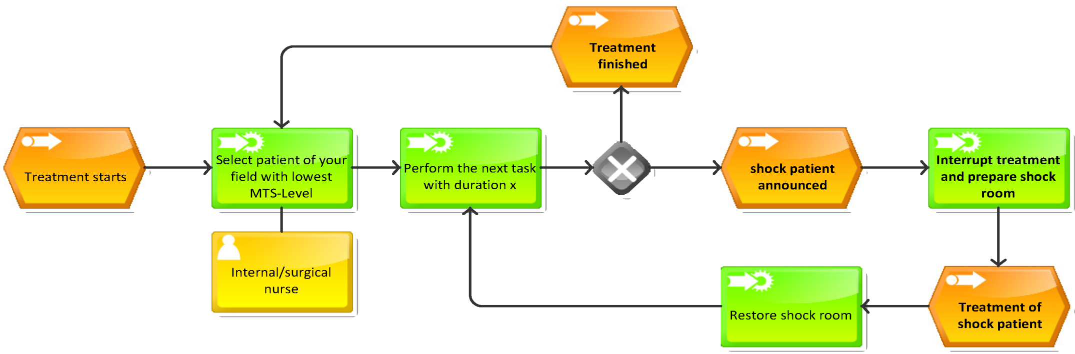


Figure 6: Simplified outline of the behavior of the agent class "nurse" (EPC)

3. Each simulation run will start on a Monday at midnight. Each phase lasts eight hours (28,000 seconds or simulation time units (STU)). The world agent will instantiate a patient every second with the probability:
$$p = \frac{Number\ of\ patients\ in\ phase\ x}{28{,}800}$$
4. The discipline (surgical/internal) and the type of arrival (alone/emergency physician) are determined randomly. Experience has shown that approximately one quarter of all patients are admitted to the ED by the ambulance.

The nurse/physician agent

During the simulation the nursing agent is responsible for the following main tasks:

- Decision-making concerning the order of treatment
- Emergency Management (determination of the process order)
- Execution of care tasks needed

The steps shown in Figure 6 are performed each run:

1. The next patient with the lowest MTS-level will be selected. All patients admitted to the ED by the ambulance are treated preferentially.
2. The list of tasks (depending on the physical impairments) will be processed. Each task took a certain period of time with random variations. Some tasks require resources of personnel and space. Available and engaged resources are permanently monitored, checked and communicated to the nurse agent.
3. In case of an emergency (MTS-level 1), the treatment of the current patient will be interrupted and the shock room will be prepared.

The patient agent

During the simulation the patient agent is responsible for the following main tasks:

- Allocation of physical impairments with the corresponding probability (See section 2.2)
- Allocation of tasks depending on physical impairment and triage level
- Modification of the triage level of a random patient object with probability p

The steps shown in Figure 7 are performed each run:

1. If a patient is generated, the assignment of one of 18 physical impairments and the MTS-level will be implemented.
2. The list of tasks will be generated according to the concrete physical impairment.
3. The patient waits for the treatment.
4. If the treatment starts, the list of tasks will be submitted to the nurse.

The triage agent

During the simulation the triage agent is responsible for the following main tasks:

- Determination of the triage level of all emergencies
- Determination of the order of treatment

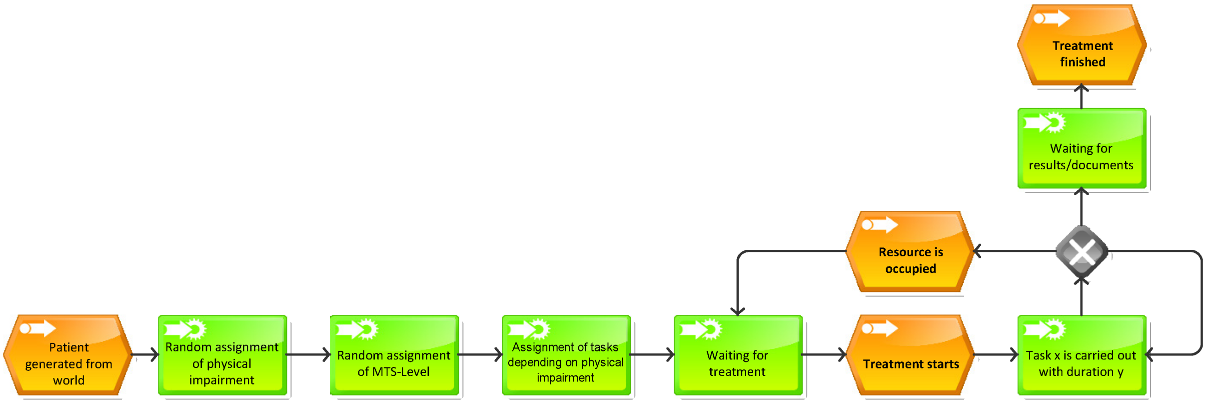


Figure 7: Simplified outline of the behavior of the agent class "patient" (EPC)

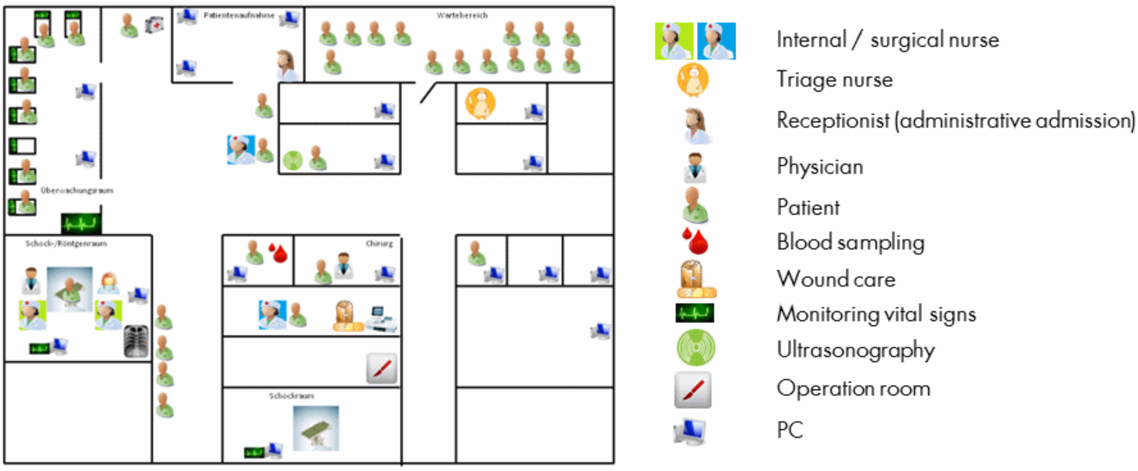


Figure 8: Floor plan of the functional areas in the ED at the University Hospital of Leipzig and the visual representation of the simulation program in SeSAm. Each simulation run generates over 30,000 emergencies with over 100 different disease profiles.

- Execution of case-specific tasks (e.g.: blood-sampling, ECG monitoring etc.)

Each simulation run in SeSAm can also be visualized observing the scene. As shown in Figure 8, the floor plan and the location of the acting agents of the ED in Leipzig can be traced easily.

3 Results

The entire simulation comprises a total of ten simulation runs. The aim of all runs was to investigate how a triage nurse and different factors influence the patient waiting times. The following parameters were modified in different scenarios:

- Order of treatment (with/without triage)
- Manning level (Reducing the number of internal/surgical staff)
- Number of patients within a defined time period (+50%/+100%)

In conclusion, the simulation runs with the use of a triage nurse could handle factors like reducing the manning level or increasing the number of patients much better. The patient waiting times of the triage runs showed entirely lower waiting times of the MTS-levels 1 and 2.

The scope of simulation run 1 was set at a value of 365 days in order to reach an adequate number of patients. In simulation run 2 it appears necessary to simulate a higher number of days in order to reach a sufficient number of patients. In each case, the waiting times of the patients were recorded and evaluated using the statistical tool R.

Simulation run 1 – direct comparison: with vs. without triage

The first simulation run focused on the impact of the method of triage on the waiting times of patients. As shown in Table 1, both runs comprise the simulated treatment of approximately 30.000 patients. The manning level depicts the number of nurses simulated in each run. In each case the use of two nurses of the specialized areas of surgery (blue) and internal medicine (green) was simulated. The triage nurse (red) is responsible for the determination of the triage level.
A particularly conspicuous aspect is the reduction of the total waiting time with triage. This is a result of many factors. For example, the additional triage nurse performs case-specific tasks (e.g.: blood-sampling, ECG monitoring etc.) and shortens the treatment time. The treatment of acute emergencies (triage level 1) does not differ signifi-

Table 1: Results of the first simulation run. In simulation run A the waiting times form administrative admission to the first treatment are pictured. In simulation run B the waiting times to the procedure for triage (first value) are displayed additionally. Especially emergency patients with a high triage-level benefit from the triage (time information in minutes – STU: simulation time unit).

	A: without triage						**B: with triage**					
scope	30,942,044 STU (358 days)						30,789,580 STU (356 days)					
manning level												
patients	29,795						29,590					
features	none						1. Additional personal: triage nurse 2. Order of treatment according to the triage level					
triage-level	**1**	**2**	**3**	**4**	**5**	**total**	**1**	**2**	**3**	**4**	**5**	**total**
1st quartile	0.02	0.02	0.02	0.02	0.02	0.02	0/ 0.02	0/ 6.03	0/ 6.03	0/ 6.03	0/ 6.03	0/ 6.03
median	0.03	9.47	8.36	8.50	8.16	6.88	0/ 0.02	0.03/ 7.00	0.05 /7.05	0.05/ 9.17	0.05/ 10.84	0.03/ 6.82
3rd quartile	0.05	42.98	42.67	41.76	40.97	39.95	0/ 0.03	2.50/ 14.50	2.87/ 25.12	3.33/ 48.77	3.34/ 68.57	2.92/ 31.40
maximum	0.15	385.5	511.9	427.4	397.0	511.9	0/ 0.02	16.20/ 56.48	36.33/ 137.9	88.25/ 370.7	84.73/ 848.7	88.25/ 848.7
total	1,064	2,087	9,746	15,266	1,632	29,795	1,049	2,030	9,599	15,232	1,680	29,590

cantly, because in both simulation runs as well as in the real system of the ED the treatment starts immediately after arrival at the ED. The total median waiting time of all MTS-levels shows little variation (6.82 min–6.88 min). However, there are considerable differences between the levels of both runs. In simulation run B the median waiting times (triage level 2) reduce by 26% towards simulation run A (7.00 min–9.47 min). In contrast, the median waiting times of the MTS-levels 4 and 5 increased by 7.9% and 32.8%.

Simulation run 2 – detecting of sudden emergencies

The purpose of this simulation run is to measure the elapsed time until a sudden emergency in the waiting area of the ED is detected. In both runs the state of health of a random patient in the waiting area will change from MTS-level 4 or 5 to MTS-level 2 with the likelihood of 0.1 percent. This random change will not occur immediately after administrative admission. The value of the period will change between 0 and 20 minutes randomly. In simulation run A (without triage) the time to the first physician contact will be determined. In simulation run B (with triage) the time to triage and the time to the first physician contact will be determined.

Both runs simulated the random event "Change of state of health of a random patient in the waiting area to MTS-level 2". It is obvious, even at first glance, that patients in run B benefit enormously from the triage (Table 2). In run B, the random change of the MTS-level of over 88% of the patients was detected immediately. The maximum waiting time of the remaining patients was at about 11 minutes. These waiting times occur whenever the triage nurse is in charge of initial examination of another patient. The situation in run A is quite different: Without the use of an experienced triage nurse critical changes in the state of health remain almost undetected. The maximum waiting time of all 256 simulated patients was over 352 minutes. Especially in life-threatening situations immediate medical intervention is needed and the first few minutes may be crucial.

4 Discussion

The complex processes of an ED could be mapped in a dynamic, detailed process model using EPCs. In particular, it was important to map the complex processes of an ED exactly in order to gain a meaningful and clearly arranged model. Thus, the most important processes were grasped and identified and served as a sound basis for the simulation. It should be emphasized that the total waiting time in simulation run 1 (Direct comparison: with vs. without triage) decreased with triage. However, there are considerable differences between the MTS-levels. By introducing MTS non-urgent patients of level 4 and 5 might be confronted with higher waiting times. The difference between the maximum waiting times of MTS-level 2 of both runs (56.48 min–385.5 min) is remarkable and might be caused by the continued monitoring of the patients by the triage nurse. In simulation run 2 (detecting of sudden emergencies) the simulated maximum waiting time of almost six hours in run A seems to be very high, but is in line with the experiences. The risk of overlooking life-threatening situations can be reduced to a minimum by consistent implementation of triage. Nevertheless, a simulation can only be as good as the underlying process model. The implemented process structures had to be simplified in order to handle the complex processes of the ED. In comparison to the real system of an ED not all effect variables and processes could be considered. For

Table 2: Comparison of waiting times of emergency patients with a sudden change of state of health. In both simulation runs the waiting times from the deterioration of the triage level of patients in the waiting area to the first treatment are pictured (time information in minutes – STU: simulation time unit).

	A: without triage	B: with triage	
scope	269,588,431 STU (3,113 days)	265,300,265 STU (3,070 days)	
manning Level			
features	1. Random deterioration of the triage level of patients in the waiting area to 2 (p=0.001) 2. Time to deterioration is uniformly distributed for a period of 20 minutes after arrival.	1. Additional triage nurse 2. Random deterioration of the triage level of patients in the waiting area to 2 (p=0.001) 3. Time to deterioration is uniformly distributed for a period of 20 minutes after arrival.	
waiting time to …	**treatment**	**triage**	**treatment**
1st quartile	0	0	0
median	9.38	0	5.07
mean	41.99	0.47	12.06
3rd quartile	53.06	0	13.13
maximum	352.3	14.46	47.76
patients	256	258	

example, the nursing staff and physicians are supported by medical students and student nurses at random intervals. Their supporting processes were not considered. More detailed process information might lead to an improved quality of the effect variables (e.g. patient waiting time) of the simulation. All statistical data considered relevant for the simulation was raised and prepared for the simulation models. Furthermore, not all statistical data was available with a sufficient degree of detail. The distribution of urgency levels date back to a pilot project under conditions different from those found out in the simulation model. More detailed process data could lead to better results – but the complexity can quickly become oversized. The simulation has made an important contribution to the implementation of a standardized procedure for assessing and monitoring emergencies and the simulation results justify the implementation of the triage procedure. The implemented simulation model offers a wider functional scope (e.g. utilization of monitoring units, utilization of staff and resources) and might be of interest for entirely different areas such as structural design of an ED. In summary, the simulation includes the essential processes and process data within and the method of agent-based simulation has proven to be an effective tool for simulating the complex process structures of an ED.

Notes

Data

Data for this article are available from the Dryad Repository: http://dx.doi.org/10.5061/dryad.2n9g6 [23].

Competing interests

The authors declare that they have no competing interests.

References

1. Gries A, Michel A, Bernhard M, Martin J. Personalplanung in der zentralen Notaufnahme [Personnel planning in the emergency department. Optimized patient care round the clock]. Anaesthesist. 2011 Jan;60(1):71-8. DOI: 10.1007/s00101-010-1830-7.
2. Prückner S, Madler C. Der Demographische Wandel. Notfall Rettungsmed. 2009 Feb;12(1):13-8. DOI: 10.1007/s10049-008-1112-y
3. Pitts SR, Niska RW, Xu J, Burt CW. National Hospital Ambulatory Medical Care Survey: 2006 emergency department summary. Natl Health Stat Report. 2008 Aug 6;(7):1-38. Available from: http://www.cdc.gov/nchs/data/nhsr/nhsr007.pdf
4. Mühlbauer B, Kellerhoff F, Matusiewicz D. Zukunftsperspektiven der Gesundheitswirtschaft. München: Lit Verlag; 2012.
5. Rutschmann O, Siber R, Hugli O. Empfehlung der Schweizerischen Gesellschaft für Notfall- und Rettungsmedizin (SGNOR) zur Triage in Schweizer Notfallstationen. Schweizerische Ärztezeitung. 2009;46:1-2. Available from: http://www.saez.ch/docs/saez/archiv/de/2009/2009-46/2009-46-701.PDF
6. Mackway-Jones K, Marsden J, Windle J. Emergency Triage: Manchester Triage Group. Manchester: Blackwell Publishing; 2005.
7. Cooke MW, Jinks S. Does the Manchester triage system detect the critically ill? J Accid Emerg Med. 1999 May;16(3):179-81. DOI: 10.1136/emj.16.3.179
8. Goodacre SW, Gillett M, Harris RD, Houlihan KP. Consistency of retrospective triage decisions as a standardised instrument for audit. J Accid Emerg Med. 1999 Sep;16(5):322-4. DOI: 10.1136/emj.16.5.322

9. Worster A, Gilboy N, Fernandes CM, Eitel D, Eva K, Geisler R, Tanabe P. Assessment of inter-observer reliability of two five-level triage and acuity scales: a randomized controlled trial. CJEM. 2004 Jul;6(4):240-5. Available from: http://www.cjem-online.ca/v6/n4/p240

10. Tanabe P, Gimbel R, Yarnold PR, Kyriacou DN, Adams JG. Reliability and validity of scores on The Emergency Severity Index version 3. Acad Emerg Med. 2004 Jan;11(1):59-65. DOI: 10.1197/j.aem.2003.06.013

11. Eitel DR, Travers DA, Rosenau AM, Gilboy N, Wuerz RC. The emergency severity index triage algorithm version 2 is reliable and valid. Acad Emerg Med. 2003 Oct;10(10):1070-80.

12. Speake D, Teece S, Mackway-Jones K. Detecting high-risk patients with chest pain. Emerg Nurse. 2003 Sep;11(5):19-21. DOI: 10.7748/en2003.09.11.5.19.c1131

13. Curtis B, Kellner M, Over J. Process Modeling. Commun ACM. Special issue on analysis and modeling in software development. 1992 Sep;35(9):75-90. DOI: 10.1145/130994.130998

14. Herrler R. Agent based simulation of processes in hospitals and other distributed, dynamic environments [PhD thesis]. University of Wuerzburg; 2007.

15. White SA, Miers D. Bpmn Modeling and Reference Guide: Understanding and Using Bpmn. Develop rigorous yet understandable graphical representations of business processes. Lighthouse Point: Future Strategies Inc.; 2008.

16. Scheer AW, Thomas O, Adam O. Process Modelling Using Event-Driven Process Chains. In: Dumas M, van der Aalst WMP, ter Hofstede AHM, editors. Process-Aware Information Systems: Bridging People and Software Through Process Technology. New Jersey: John Wiley & Sons; 2005. DOI: 10.1002/0471741442.ch6

17. Schaaf M. Modellierung und Evaluation einer Simulation der Pflegeprozesse in der Zentralen Notaufnahme des Universitätsklinikums Leipzig AöR [Diploma thesis]. University of Leipzig; 2011.

18. University Hospital Leipzig. SAP Database triage pilot project. 2009.

19. Leipzig University. Jahresbericht 2010 [Annual Report 2010]. Universität Leipzig; 2011. Available from: http://www.zv.uni-leipzig.de/fileadmin/user_upload/Service/oeffentlichkeitsarbeit/Jahresberichte/jahresbericht_2010.pdf [accessed 2012 Aug 21]

20. Charfeddine M, Montreuil B. Toward a conceptual agent-based framework for modelling and simulation of distributed healthcare delivery systems. Montreal: CIRRELT; 2008. Available from: https://www.cirrelt.ca/DocumentsTravail/CIRRELT-2008-09.pdf

21. Wooldridge MJ. An introduction to MultiAgent Systems. New Jersey: John Wiley & Sons; 2009.

22. Nikolai C, Madey G. Tools of the Trade: A Survey of Various Agent Based Modeling Platforms. Journal of Artificial Societies and Social Simulation. 2009;12(2):2. Available from: http://jasss.soc.surrey.ac.uk/12/2/2.html

23. Schaaf M, Funkat G, Kasch O, Josten C, Winter A. Data from: Analysis and prediction of effects of the Manchester Triage System on patient waiting times in an emergency department by means of agent-based simulation. Dryad Digital Repository. 2014. DOI: 10.5061/dryad.2n9g6

Corresponding author:

Michael Schaaf
Institute for Medical Informatics, Statistics and Epidemiology (IMISE), Härtelstraße 16–18, 04107 Leipzig, Germany
michael.schaaf@imise.uni-leipzig.de

Please cite as
Schaaf M, Funkat G, Kasch O, Josten C, Winter A. Analysis and prediction of effects of the Manchester Triage System on patient waiting times in an emergency department by means of agent-based simulation. GMS Med Inform Biom Epidemiol. 2014;10(1):Doc02.
DOI: 10.3205/mibe000151, URN: urn:nbn:de:0183-mibe0001518

This article is freely available from
http://www.egms.de/en/journals/mibe/2014-10/mibe000151.shtml

Published: *2014-02-18*