Process flows of an emergency department. How process modelling and simulation can help improve the efficiency and quality of patient care

Yannik Angler [1], *Astrid* Loßin[2], and *Olav* Goetz[2]

[1]Detecon International GmbH, Cologne, Germany
[2]APOLLON University of Applied Science GmbH, Bremen, Germany

Abstract. Emergency departments are the first point of contact for life-saving care worldwide. Despite this importance in patient care, emergency departments face a number of shortcomings. For example, emergency departments have been struggling for many years with a lack of resources, low levels of digitalization, or unregulated access to emergency departments. Thoughtful process analysis using discrete event simulation (DES) can support the implementation of better processes to improve quality of care sustainably. Based on empirical data obtained through observations, expert interviews, process analysis, and time studies, the authors modelled and simulated the flow of care in a general hospital's emergency department using a stochastic DES model. The results of the DES study show that digital upgrades and additional staff resources, in particular, can reduce process times in terms of length of stay and waiting times. One can conclude that discrete event simulation is a suitable tool to realistic model and simulate complex systems such as emergency departments, and derive meaningful improvement potentials. In the future, the potential of digitalization concerning process flows should be considered more often in DES studies.

Key words: emergency department, computer simulation, discrete event simulation, process management.

1 Introduction

Emergency departments deal with many difficulties: a lack of resources, low remuneration, slow digitalization, and unregulated access. At the same time, the emergency department is a very important junction point in hospitals, a place of lifesaving interventions and the beginning of many clinical pathways. That is the reason why emergency departments need a good quality of service and process. Process management is a useful method to support process development. Structures and processes should be analyzed in their current state to find potential appropriate target states that provide a higher level of efficiency in human-resource allocation, patient streams, workflows, and additional resources. Discrete Event Simulation (DES) is a computer-based method to analyze processes by treating them as a series of events [1]. DES is a method to model clinical pathways, to estimate patients' satisfaction and to maximize economic efficiency [2-4]. The aim of this paper is to analyze the efficiency of process flows in an emergency department of a German general hospital by using DES.

2 Material and methods

This simulation-based analysis of process flows took place in an emergency department of a German general hospital with less than 300 beds in a rural area. The main areas of treatment are internal medicine, vascular surgery, orthopaedics, urology, ENT surgery, anaesthesia and intensive care. The emergency department ensures medical care for 24 hours a day and seven days a week. Based on an observational study, a general overview of the operations, conditions, activities, and patient flows in the emergency department was developed. This is a prerequisite for preparing the simulation. It was especially important to understand patients' prioritization. The general hospital applies the Manchester triage system that uses the coloured categories - red, orange, yellow, green, and blue to define the urgency of patient's care. Based on the MTS system, general nurses care for the blue, green, and yellow patients. Nurses with training in critical care medicine, care for the orange and red patients, due to their higher severity.

Table 1. Manchester triage system. Source: [5].

Colour	Target waiting time
Red	none
Orange	10 min.
Yellow	60 min.
Green	90-120 min.
Blue	90-120 min.

Using the results of the local observation and of the interviews with the medical staff the patient's journey through the emergency department can be retraced as shown in the following Fig. 1.

Data **collection** took place by measuring patient flow times within a period of three weeks during different days of the week. Time was measured for every step as shown in Fig. 1. Times measured were divided in waiting times and activity times [6]. They both together defined patients' length of stay. Waiting times and activity times differ depending on the colour of the priority class. Red and orange patients generally receive faster treatment than the other patients due to urgency of care. The green and blue patients were included in one group because of their quite similar needs of resources. The authors' standard process is focused on this group, as it is the largest one.

Based on the three-week survey phase, the authors determined a runtime of 120 hours to represent the survey period from Monday to Friday over eight hours each day in the simulation model. The number of replications was set at 30 replications. After completing the 30 replications, the authors compared the data from the time study and the baseline model using the mean to test the validity of the model and its degree of approximation to reality (see Fig. 2). For verification, MedModel provides automated debugging, which was used to detect and report conceptual errors.

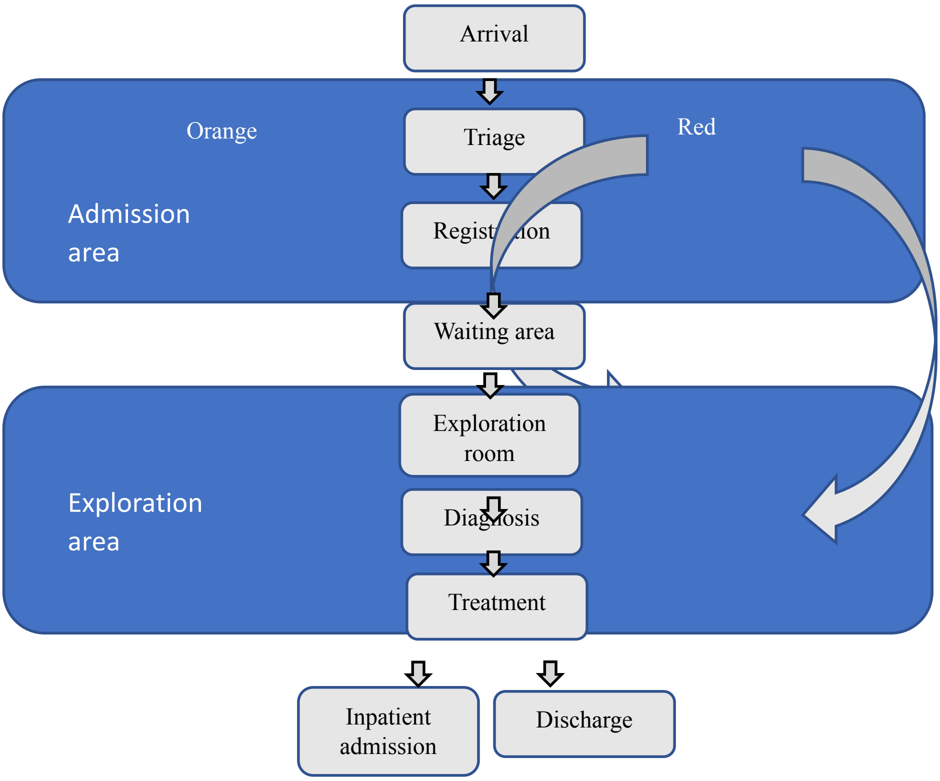


Figure 1. Standard process: Patient's journey through the emergency department. Source: own.

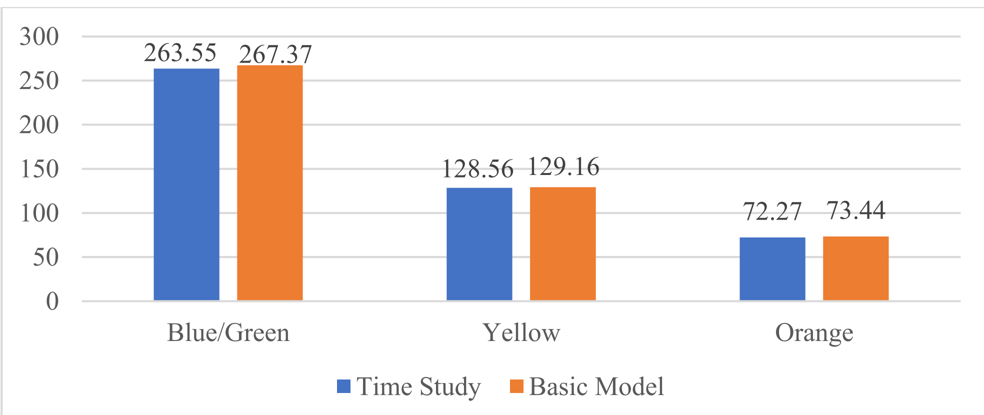


Figure 2. Time comparison between time study and basic model by total mean value in minutes. Source: own.

3 Results

3.1 Results from the basic model

3.1.1 Basic model: Length of stay and waiting time

Analysis of the model showed that blue/green patients had an average length of stay of 267.37 minutes, which is equivalent to 4.45 hours. Yellow patients left the ED after 129.16 minutes (2.15 hours), while orange patients spent an average time in the system of 73.44 minutes (1.22 hours). In terms of waiting times, it was found that waiting times in the blue/green and yellow MTS levels exceeded the 30-minute mark, which may increase the risk of higher patient dissatisfaction. Table 3 provides an overall summary of the composition of time parameters in the system.

Table 2. Average time parameters of patients in the system (in minutes). Source: own.

	Entities	Average Length of Stay	Average Waiting Time	Average Duration of Processing
Blue/Green	20	267.37	52.94	212.87
Yellow	10	129.16	36.57	91.74
Orange	5	73.44	16.56	56.88

In particular, the length of stay of blue/green patients must be critically examined. According to British study published in the Emergency Medicine Journal, the risk of death increases within 30 days if the length of stay exceeds five hours [7]. In general, the British Ministry of Health and other countries such as Canada and Australia set a target of four hours for the length of stay, which should not be exceeded [8].

3.1.2 Basic model: Utilization of personnel capacities

The results of the basic model showed that the degree of utilization of the physicians and the blue/green/yellow nurses could be considered relatively high. Since they are regarded as mainly responsible for the time-intensive treatment and diagnostic steps, a correlation can be derived between the patients' length of stay and the degree of utilization of the physician resources.

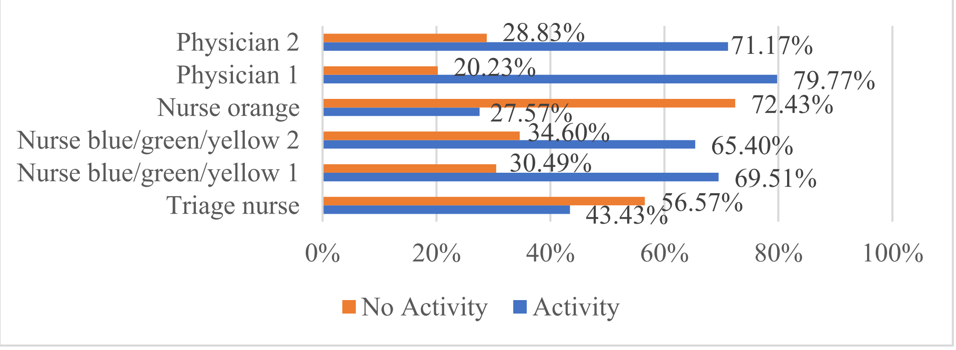


Figure 3. Utilization of personnel capacities in the emergency department Source: own.

3.1.3 Basic model: Utilization of infrastructure capacities

The results of the simulation of the basic model show that the utilization of the infrastructure capacities diverges intensively. While the two examination and treatment rooms and the waiting area are highly utilized, rooms such as the two shock rooms, the care rooms for aseptic treatment or the triage room are only used to a low or moderate extent. Based on the simulation results, the question is whether a fixed allocation of rooms in the emergency department is reasonable and whether, for example, one of the two shock rooms should also be used for yellow patients in order to achieve a higher utilization.

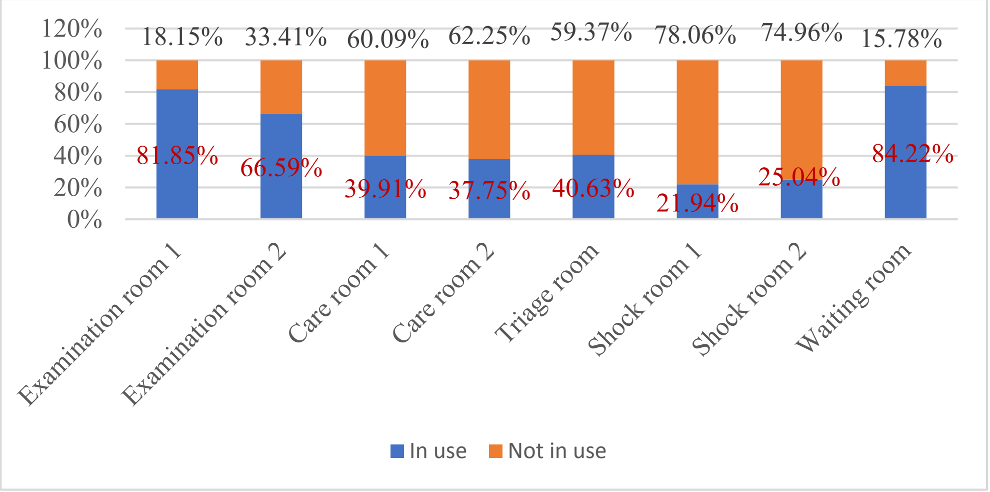


Figure 4. Utilization of infrastructure capacities in the emergency department. Source: own.

3.2 Results from the scenarios

3.2.1 Scenarios for system improvement

Based on the results of the basic model and consultations with the medical staff of the ED and other health experts, five scenarios were defined. The present simulation study tested them in order to prove their effects on a reduction in length of stay and waiting times as well as an improved utilization of staff and infrastructure.

Scenario 1: Making a shock room available for yellow patients.
Scenario 2: Establishment of a physician assistant.
Scenario 3: Establishment of an additional physician.
Scenario 4: Digital upgrade of the emergency room by electronic triage systems, messenger services, or emergency information and documentation assistants.
Scenario 5: Establishment of an additional nurse for the MTS level blue/green/yellow.

3.2.2 Scenario: Length of stay and waiting time

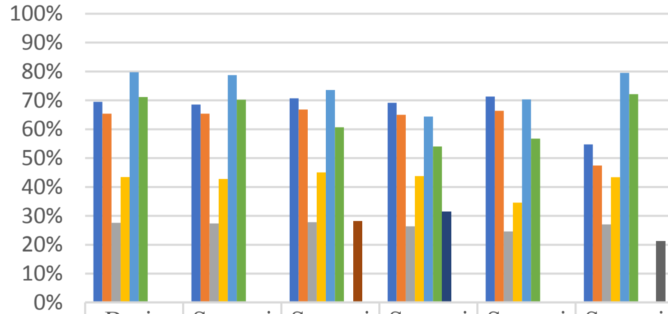
Table 3 shows that scenario 3 (establishment of an additional physician) and scenario 4 (digital upgrade of the emergency department) led to a significant reduction in waiting times and lengths of stay for all patient categories. Compared to the baseline model, the length of stay in scenario 3 decreased by 8% for blue/green patients, 6% for yellow patients, and 4% for orange patients. Scenario 4 can be used to achieve even greater improvements to reduce length of stay. For example, compared to the basic model, the length of stay can be reduced by 10% for the blue/green patients, 12% for the yellow patients, and 15% for the orange patients. The digital upgrade for the blue/green patients can therefore achieve the target of a maximum length of stay of four hours. An overview of the overall results of the various scenarios can be seen in Table 3.

Table3. Comparison between basic model and scenarios according to mean value (in minutes). Source: own.

	MTS-Level	Entities	Length of Stay	Waiting Time
Basic Model	Blue/Green	20	267.37	52.94
	Yellow	10	129.16	36.57
	Orange	5	73.44	16.56
Scenario 1	Blue/Green	20	267.86	53.36
	Yellow	10	129.02	37.23
	Orange	5	74.14	17.43
Scenario 2	Blue/Green	20	248.80	33.54
	Yellow	10	129.22	36.43
	Orange	5	74.47	17.68
Scenario 3	Blue/Green	20	246.35	32.15
	Yellow	10	121.21	29.53
	Orange	5	70.84	14.38
Scenario 4	Blue/Green	20	239.91	33.66
	Yellow	10	113.97	29.45
	Orange	5	62.51	14.00
Scenario 5	Blue/Green	20	254.83	41.06
	Yellow	10	124.88	30.57
	Orange	5	73.51	16.72

3.2.3 Scenario: Utilization of personnel capacities

The results draw attention to the fact that in all scenarios an improved dispersion in the utilization of medical staff was generated (see Fig. 5). At the same time, improved utilization dispersion has a shortening effect on the length of stay, as proven by scenarios 2, 3 and 4. It was also found that digitalization (scenario 4) can make processes leaner, more efficient and thus faster. Processes supported by electronic triage systems, messenger services or emergency information and documentation assistants, among others, relieve the existing staff without having to increase personnel capacities. Based on scenario 5 (establishment of an additional nurse), it was shown that an additional nurse for the high patient volume of the MTS categories blue, green, yellow leads to a lower workload per nurse, which can be accompanied by higher time capacities for improved care.



	Basic Model	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Nurse blue/green/yellow 1	69.51%	68.54%	70.70%	69.18%	71.30%	54.74%
Nurse blue/green/yellow 2	65.40%	65.41%	66.81%	64.98%	66.41%	47.45%
Nurse orange	27.57%	27.39%	27.83%	26.40%	24.60%	27.02%
Triage Nurse	43.43%	42.79%	45.07%	43.77%	34.56%	43.41%
Physician 1	79.77%	78.74%	73.59%	64.40%	70.34%	79.52%
Physician 2	71.17%	70.21%	60.68%	54.02%	56.72%	72.14%
Physician 3	0	0	0	31.48%	0	0
Physician Assistant	0	0	28.19%	0	0	0
Nurse blue/green/yellow 3	0	0	0	0	0	21.20%

Figure 5. Comparison of staff utilization between the basic model and the scenarios. Source: own.

3.2.4 Scenario: Utilization of infrastructure capacities

As a result of an improved distribution of infrastructure utilization, an increase in utilization to 48% was achieved for shock room 2 in scenario 1, compared to 25% in the basic model (see Fig. 6). The utilization of the care rooms was also increased slightly, while the utilization in the highly frequented examination rooms decreased. Consequently, it can be seen that scenario 1 leads to better distributed utilization of infrastructure resources, i.e., the available resources can be used more efficiently.

4 Discussion

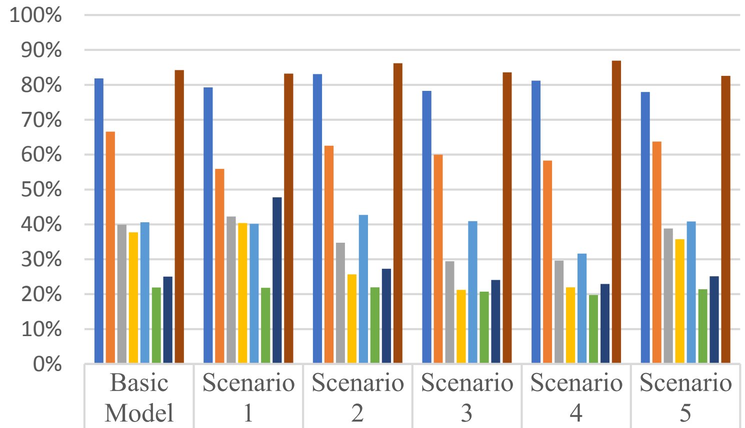
By comparing the tested scenarios with the basic model, initial recommendations for action could be derived for the emergency department of the project hospital.

Recommendation 1: Digital upgrade of the emergency department to reduce length of stay, waiting times, and reduce staff workload.

Recommendation 2: Staffing upgrades to the emergency department to reduce length of stay, waiting times, and reduce staff workload.

Recommendation 3: Expanding the use of a shock room for the yellow patient category to achieve improved utilization.

In the course of the scenarios examined, the simulation study focused on future development of the healthcare system influenced by digitalization. The importance of digitalization for the healthcare system will steadily increase in the future. Therefore, it is important that more and more simulation studies also focus on the potential of digitalization. There are many studies dealing with the modelling and simulation of workflow processes in the emergency department [9]. Until now, only a few simulation studies have been identified that focus on the benefits of digital solutions in the emergency department. Yet, modern emergency departments already use a range of information and communication technologies that are closely linked to patient-related information flows[10].Information and communication technologies (ICTs) have the potential to significantly address emergency department crowding, but important potential improvements are routinely missed because ICTs are not included in simulation studies [9].



	Basic Model	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Examination room 1	81.85%	79.27%	83.07%	78.28%	81.20%	77.96%
Examination room 2	66.59%	55.92%	62.57%	59.98%	58.28%	63.77%
Care room 1	39.91%	42.25%	34.73%	29.43%	29.61%	38.81%
Care room 2	37.75%	40.38%	25.66%	21.23%	21.95%	35.75%
Triage room	40.63%	40.16%	42.71%	40.92%	31.62%	40.86%
Shock room 1	21.94%	21.85%	21.97%	20.75%	19.77%	21.42%
Shock room 2	25.04%	47.74%	27.29%	24.07%	22.92%	25.13%
Waiting room	84.22%	83.22%	86.21%	83.58%	86.93%	82.56%

Figure 6. Comparison of infrastructure utilization between the basic model and the scenarios. Source: own.

Discrete event simulation should also continue to develop in the course of digitalization. Increasing digitalization means that more and more real-time data is available to hospitals and their emergency departments more and more quickly. However, hospitals are often unable to make use of this real-time data. This is also one of the core problems of traditional DES models, most of which are developed based on historical data [11]. However, the increased use of historical data often leads to inaccurate and less reliable assumptions about the future [12]. This is exactly where online DES comes in. This is because in an online DES, the model is run in parallel with the real world using real-time data [13]. Continuously updating the online DES model requires Internet of Things (IOT) devices to ensure real-time data collection and analysis [13]. The ability to map every sub-process in a real time system with a variety of IOT devices means that more accurate predictions can be made for future impacts in a system. Regardless, there are still numerous challenges associated with implementing an online DES model, starting with the expandable level of digitalization across the board in many hospitals. Ethical and data protection aspects also need to be comprehensively clarified before implementation.

5 Conclusion

The research study proves that discrete event simulation is a suitable tool for realistically depicting a complex system such as the emergency department and deriving meaningful potential for improvement from it. The basis for this is a suitable simulation software, which makes it possible to map the specific processes of an emergency department in a fine-granular way. In the future, the potential of digitalization must be part of simulation studies on a higher scale. ICT already offers numerous opportunities for hospitals and especially for emergency departments to provide comprehensive support for medical staff and their processes. Also, the use of online DES models, which simulate the processes from the real system using real-time data, seems to be an interesting approach for future simulation projects and its feasibility should be investigated further.

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