simulation, optimization, healthcare processes

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OPTIMALIZATION OF HEALTH CARE PROCESSES WITH THE USE OF SIMULATION

1. WHAT IS SIMULATION ?

Simulation is the imitation of actual running process in time [1]. By emulating logic and randomness of the process, such as the flow of patients through the various departments of medical facilities and random duration of each type of treatment, simulation is a valuable tool for the evaluation and comparison of the proposed changes to the process [2]. Impacts of process changes, such as increasing the number of doctors are assessed by performance measurement, so for example the amount of time (simulated) that patients waited for examination or treatment [3]. During the course of the simulation, big amount of performance measurements and data are recorded for statistical analysis. In organizations either providing services or producing goods is their efficiency affected by various deficiencies - different kinds of waste, ineffective resources utilization (material, energy, people, equipment and time) [4]. These types of waste are undesirable and must be eliminated [5].

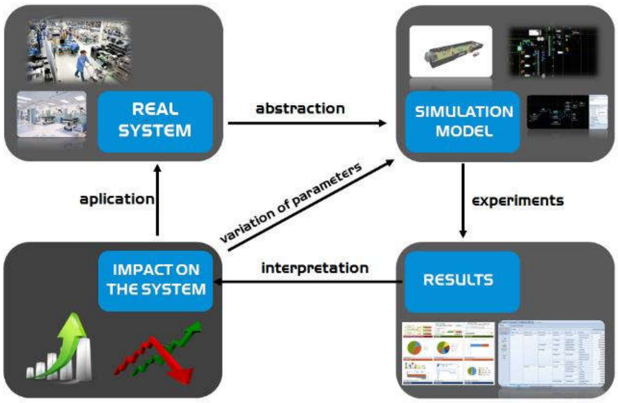

Fig 1. The principle of simulation [1]

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1.1. The use of simulation in healthcare

Simulation has a broad potential of applications in healthcare, which may be classified into several main directions. General classification of simulation in healthcare is as follows [6]:

- **Clinical simulation** – used mainly for studying, analyzing and replication of some diseases behavior, including biological processes in the human body.
- **Operating simulation** – used mainly for capturing, analyzing and studying the health operations, service provision, planning, healthcare operational processes and patient motion.
- **Management simulation** – used primarily as a tool for management purposes, decision making, policy implementation and strategic planning.
- **Training simulation** – used for training and educational purposes, where virtual environments, virtual and physical objects are widely used and enrich simulation experiments.

Managerial and operational direction of the simulation are closely linked. Together, they form the major components for the management of healthcare processes.

The above classification is just the starting point, that only indicates huge space of simulation application for healthcare domain. In each of these directions can be simulation used for analysis and design, education and training, research and communication purposes.

Brailsford classifies medical simulation models into three groups [7]:

- The models of the human body, often referred to as models of disease, including the biological processes of healthy subjects.
- Models for tactical purposes at the unit level of health care (clinics, departments, hospitals).
- Models for strategic purposes involving the whole system models which often do not model all individual patients.

All these classifications show how large the space and potential applications of simulation in healthcare is. However, the current research and practical medical simulations are rather at an early stage compared with the engineering and production departments. The full potential of simulation of health care has yet to develop.

1.2. DES in health care

On the basis of the impact and frequency of application is identified relatively few simulation techniques of relevance. These groups consist mainly of mainstream simulation methods and simulation of algorithms based on artificial intelligence [8]. The same way as many tools and methods, and discrete event simulation (DES) has appeared from the manufacturing sector. DES first language was developed by K. D. Tocher for United Steel Corporation in the late 50s. Since then sequentially programming languages developed over GPSS, Simscript, Simu, SLAM, SIMAN Arena to Simio. At the beginning it is necessary to define a discrete event simulation.

Fig 2. Simulation methods

Banks defines simulation as an operation imitating of the real process or system over time. DES is a specific approach to simulation processes and systems in which the system state changes immediately at time points, such as the arrival of a customer or activities completion [9]. This approach is particularly suitable for queuing systems modeling. Of course, also many health care processes can be understood as queuing systems, in which are mainly patients those who are waiting in the queue.

Robinson discribes a key reason for using DES as the need to model processes that are subject of variability, and which are linked, resulting in complexity [10]. Variability may be predictable (e.g. shift changes) or unpredictable (e.g. patient's arrival patterns and times of consultations and treatments). Most of the processes are the subject of a number of sources of variation, which are linked (e.g. patterns of arrivals, triage times, times to first treatment, etc.), the process is complicated. As a result, it is difficult to predict the effectiveness of the process, therefore, simulation should be chosen.

The complexity appears not only from the scope of the process that is under investigation, but also from dynamic interaction and feedback between the various elements of the process. For this reason, the underlying assumption of DES is that the processes are subject of variability and they are interconnected and complex. Queues, which appear in the process and their efficiency (process flow) is difficult, if not impossible, to predict without simulation.

DES is used primarily as a mean of testing whether the proposed procedure is carried out as expected. At the same time they seek means of improving the process. The common benefits of using DES in a manufacturing and health care context, are in the reduction of risk, better understanding of processes, reduction of operating costs, lead time reduction, quick changes of machines, capital costs reduction and better customer service. These benefits, however, can be easily translated to other contexts, such as services and healthcare. DES implementation in health care could not be so easy. The two main issues that are mentioned in relation to management and stakeholders, are the level of their involvement in simulation studies and the problem of managing conflicting interests of different stakeholders [7].

1.3. The basics of DES in health care

An important advantage of using discrete event simulation to model medical devices over other modeling techniques, which include linear programming or Markov Chain analysis is the ability to model the complex patient flows and scenarios testing and "what if" changes in the rules and patient flow management [11]. The success or failure of simulation studies in the area of health care often depends on compliance with the standard sequence of steps. Law and Kelton outlined the key steps that are necessary to perform a successful simulation study [12]. These steps include:

- Problem formulation and study plan.
- Data collection and conceptual model design.
- Model validation.
- Design of a computer model.
- Model verification.
- Design of experiments for problem solution.
- Pilot runs using a computer model.
- Statistical data analysis obtained from the pilot runs.
- Interpretation of the results with respect to the system.

Key issue for the success of simulation studies of health care is careful formulation of the problem and the involvement of all stakeholders. When simulating production systems, the model and data errors can lead to unexpected costs and poor performance. In health care, such errors can lead to life loss of patients. It is therefore not acceptable any space for errors in the design and application of medical simulation models. These restrictions provide obstacles and barriers that can be overcome only with the highest attention to detail and accuracy, as well as communication between all stakeholders.

1.4 Simulation inputs and outputs

Tab 1 introduce the primary inputs to the model. The simulation terminology, some of them are referred to as controllable variables or decision variables, because their management may change and affect the performance of the process. All other variables are called uncontrollable and are perceived outside the control of management. Various analyzes can often be enforceable just using these variables, which include, for example, sensitivity analysis (e.g.: What if more patient arrive at the same time?).

Tab 1. Decision variables and simulation inputs

No. of :	Time distribution of:
• Receptionists • Medical assistants • Physicians and nurses • Treatments per worker • Ambulances per worker	• Registration • Food preparation • Treatment • Next process prescription • Ambulance cleaning

Fig 3 shows some of the outputs of the performance measurements obtained from the simulation. These data can be collected and analyzed in whole or by employees, type of treatment, and time of day.

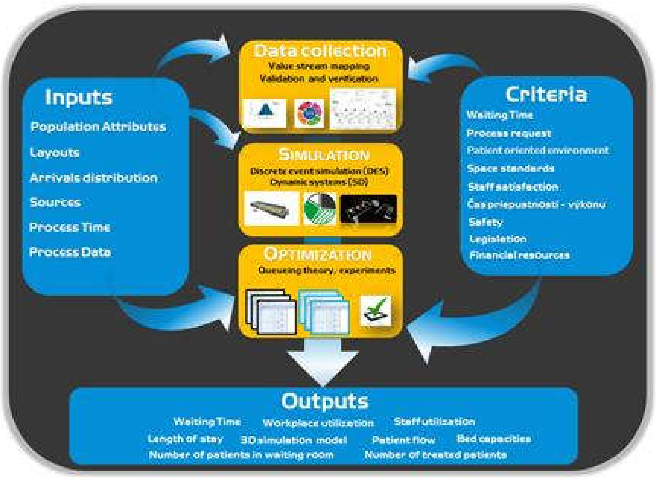


Fig 3. Inputs, criteria and outputs of simulation

1.4. ED simulation models

Simulation discrete event models can capture the complex patient flow in existing health care facilities, as well as analyze the impact of the new rules, policies and flow of patients. These flows are typical for ED, where patients arrive almost always without scheduled meetings and require treatment over a large and diverse set of diseases and conditions that range from minimal (e.g. a slight sports injuries) to fatal (e.g. heart attacks, gunshot wounds). Although the patient's arrival patterns are highly unpredictable the sequence of treatment can be effectively managed by medical staff.

From the above reason, and given change in direction of the flow of patients, it is possible to minimize patient waiting time and increase the utilization rate of employees. Limited access to primary care led to an extreme rise in the use of emergency departments worldwide. Overcrowding in emergency departments has been recognized by national health groups and regulatory authorities, which include the American Hospital Association (AHA) and the Joint Commission on Accreditation of Healthcare Organizations (JCAHO) as a major public health problem. All this has led to a significant increase in the use of discrete event simulation and modeling of ED in the past decade.

Takakuwa and Shiozaki proposed a procedure for scheduling urgent operations to minimize the waiting time of patients [13]. Sinreich and Marmor developed a general simulation tool for emergency departments that is flexible, intuitive, easy to use and contains the default values for most parameters of the system. They also describe the steps for creating a discrete event simulation tool to determine the best and most suitable configuration for the emergency departments [14].

The key indicator of the health services used by the emergency department is patient waiting time. Garcia analyzed the impact of the fast-track to reduce queue waiting time of low acute patients [15]. Patients are typically triaged according to their acuity, patients with low acuity are waiting excessively long time. Fast Track front is used to treat certain level of patient acuity (in this case, non-acute patients). They found out that fast-track stream that uses small amount of resources could lead to a significant reduction in patient waiting times.

Increased waiting time change the perception of the quality from the patient view [16]. It also requires more space (waiting room) and long waiting times are the cause of many patients leavings.

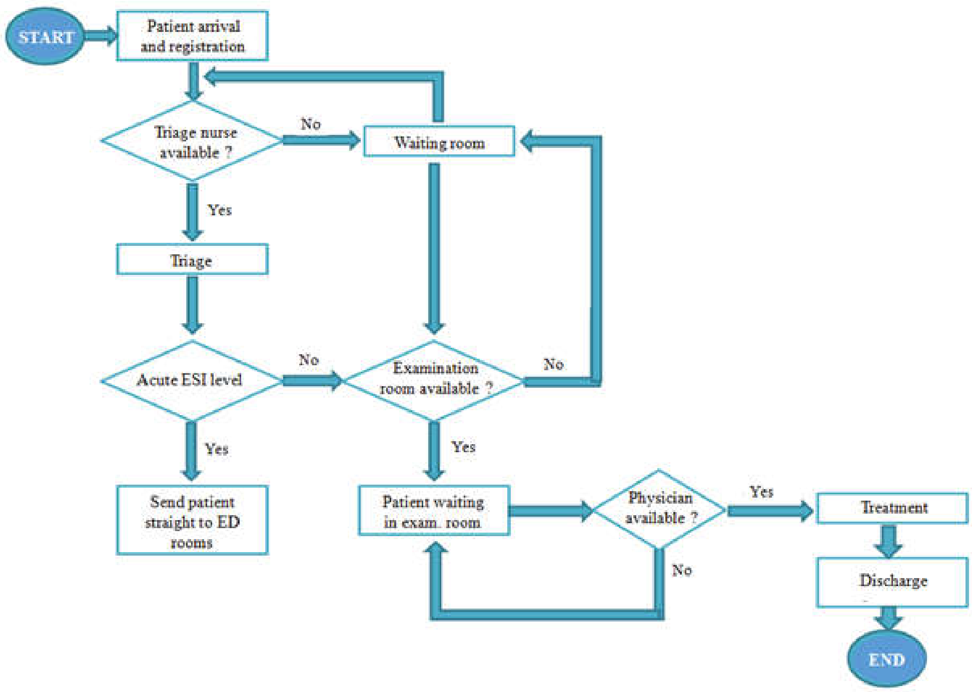


Fig 4. The basic steps of ED treatment process simulation

If we want to get model of real system, we have to consider also the restrictions. The model should:

1. Reflect processes of care that contribute significantly to the ED overcrowding to facilitate predictive power of forecasts.
2. To minimize the input data requirements, to facilitate the use of its generality between institutions.
3. Be implemented as quickly as possible to enable real-time predictions.

An interdisciplinary team composed of health care professionals, managers, medical informatics and biostatistics create a model. Development continues iteratively until all team members will not agree with the model. The design and construction of the final ED model is in most cases the same, only with minor adaptations and modifications (Fig 5).

Patient arrivals (A). These arrivals vary and depend on the time of day and day of the week. We are trying to replace arrival patterns by the theoretical distributions which suitability we must verify (e.g. a goodness of fit or Chi square). The time between the patient's arrival in the US in emergency departments have usually exponential distribution.

Left without being seen (B). Some patients leave ED without having been seen by physicians. These decisions are influenced by long waiting period. This process is represented by using a regression model of waiting. The number of patients in the waiting room is an independent variable [17]. Whether the patient leaves ED without physician seeing is the dependent variable. Simulation transforms the probability logarithm of leaving ED without treatment for each patient. Then it uses a random Bernoulli experiment to determine whether the patient leaves.

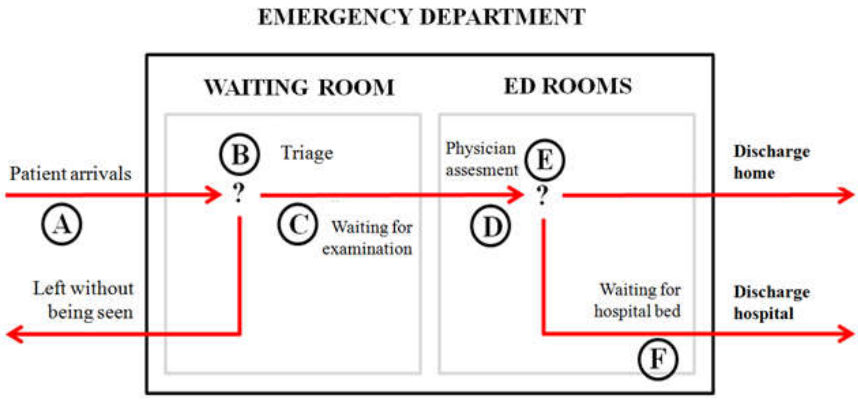


Fig 5. Patient flow through emergency department

Triage - Assign an acuity level (C). Patients are usually classified by the level of acuteness. In the model, the triage is represented by chance, respectively by the probability that the patient will belong into a given group of acuteness (ESI 1-5). The simulation model will place the most urgent patients into ED beds immediately, regardless of the availability of beds. This provides a mechanism by which under extreme operating conditions may be the capacity exceeded. Simulation retains all other patients in the waiting room and establishes their order of treatment according to the degree of acuity or by the sequence of arrival.

Physician assessment and treatment (D). It is believed that the most acute patients generally require the provision of time-consuming and broader health care. Normal, Gamma and Weibull distribution commonly describe time data patterns. The simulation uses a single normal distribution within each group representing the acuity of the patient and physician assessment duration of the treatment.

The decision-making about admission to the hospital (E). Most sick and most acute patients are admitted to the hospital more often. After completion of the physician assessment and treatment for each patient, simulation is using Bernoulli random test to determine whether it should be the patient admitted or not. Simulation immediately deprives ED ambulance from treated and completed patients that are ready for acceptance, while maintaining those patients waiting for a available hospital bed.

Hospital beds (F). Getting in patients that are already admitted to the hospital is usually one of the main reasons of ED crowding. It should be taken into account that some hospital processes such as schedules of operating rooms, affect the bed availability. Simulation favors admission of patients to hospital beds by the Boarding time.

Most of predictive simulation models implementations are made using the standard C programming language. Simulation generates random numbers using Mersenne Twister algorithm, which has been statistically verified for simulation.

1.5. Simulation in health care and its potential areas and future trends

Simulation in healthcare primarily allows the replication of the facts and examination of possible changes and situations that were not really possible. This can be achieved without high investments in systems development, training, and equipment purchasing [18].

Moreover, simulation in health care may be extended beyond its traditional role of scenarios comparison and workflow visualization. The simulation model can be incorporated as a part of ongoing efforts of performance monitoring and efficiency improving. In this role the simulation model is developed not only for the runs and experiments, but is rooted in the information systems of health care facility [19].

The true benefit of simulation is noticeable only when simulation models are fully integrated into the normal structure of health care provision, i.e. into the existing information system that supports the daily operations of health care provider. The essence of the vision is to consider simulation as a tool for the management of a single set of experiments, which is considered as a significant change. The real vision is to make simulation models that run parallel with other applications as a routine part of everyday working environment.

With this approach, the efficiency of health care becomes today's primary objective, while the future may require even higher requirements. In addition, with rapid changes of health care system variables (technology, finance, policy, service requirements, market, etc.), the effectiveness of health care is becoming moving target that is necessary to revise and re-address. Heed warnings from skeptics from past about the resistance against simulation had disappeared. Today, health care shows more maturity and the need of simulation plays an important role in solving public health problems. In addition, the current economic situation, policy changes and the environment in which healthcare is provided, are ripe for the institutionalization of simulation as a standard tool for management and control support of healthcare service delivery [20].

1.6. The potential of simulation in health care

Simulation in health care can be considered as an effective tool, technique or method. Improvements in some aspects of next chapters will lead to the main goal – to increase the efficiency of health care.

1.6.1. The development of information technology

Development of a national electronic health records (EHR) has created a unique opportunity for health care systems around the world to move to electronic medical practice (eHealth), and possibility of the economic benefits.

But the way for benefits from eHealth-U leads through the design of innovative medical processes and redesign of existing processes and practices that deal with the changes resulting from the adoption of new technology. The work [21] estimates the potential savings and the cost of EHR in the US and found that the effective implementation of HER (interoperable with other systems) could ultimately save more than $ 81 billion annually. This savings is achieved by improving the effectiveness of health and safety. However, the authors recognizes that it is unlikely to be realized without related changes in the health care system [21]. This means that the application of simulation in medical redesigning of existing operational processes and IT arrangement has a major potential for scientific research.

1.6.2. Decision support

Medical personnel (decision-makers) need reliable operational tools that support them in decision-making at critical moments, costs reduction, patients waiting time reduction, help them predict future patients arrivals and provide visualization to enable them to prepare personnel and other resources for high-quality provision of patietns health care at the right time [22]. These tools should also facilitate with decision making evidence and informative environment. Simulation models, especially those with transparent structure that leads to the core variables that can be easily understood and trusted by people (decision-makers), are a useful tool to support decision making, communication and discussion of ideas, policies and scenario analysis [6].

1.6.3. Training and quality

Adequate training of physicians has a direct impact on service quality. This will reduce errors and promote the adoption of best practices. Trainings of medical personnel (doctors, administrators and managers) are costly, time consuming and require a commitment and dedication, which are usually taken for a reasons of time.
Simulation can [6]:

- Successfully enhance and improve the knowledge of doctors.
- Make acquaintance with the new procedures and processes.
- Prevent errors that are caused by lack of training and practical experience.

1.6.4. Complexity

The complexity of the medical procedures increases exponentially with various services, for example, laboratories are being moved out of hospitals that had resulted into extreme mobility of patients due to competition on the free market. Modern hospitals are complex systems of distributed subsystems with complex medical processes, human interaction and operating procedures. In these hospitals, citizens can easily plan their health care based on a shorter waiting time, excellent quality and many other factors that lead them in their local, regional or even national boundaries. This makes the process of health care related and more complex and simulation can be a way of : How to resolve the complexity. This means that the complexity of healthcare systems makes the simulation as a potential tool for medical analysts.

1.6.5. Process improvement

In most medical simulation projects, for the purpose of efficiency, is the main objective patient waiting time reduction. Waiting for the date of service delivery and just waiting for the health service is an important indicator of efficiency. The waiting time is the cause of many problems that is health care facing today. Increased waiting time affects the patient's quality perception [16], it also requires more space (waiting room) and long waiting periods that are the cause of many leavings.

1.6.6. Data collection

The simulation model can only be as good as the input data, so data collection is one of the main challenges in health care. In healthcare simulation developers often do not have enough input data for the simulation models, which then usually bring only approximate results.
Data collection is therefore a major challenge because:

- Historical data may not be available in a useful form.
- Data collection should take place over a longer period of time.
- Communication and interviews with health professionals and the purpose of verification is also a challenging task due to their time availability.
- Input data must be realistic and complete (not approximate), based on the ongoing operations of the system (e.g. From information systems).

Some hospitals may have a more agile and dynamic staffing where simulation that is based on real data can play an important role, and that is the prediction of the number of nurses and staffing on a daily basis, the distribution of nurses between hospital and home care, and many other proposals arising from benefits of simulation model based on accurate and real data. An ideal data collection may require the integration of simulation models with hospital information systems that support daily operations. As other applications (e.g. meeting scheduling, operating rooms reservation, etc.) generating new data, these data are automatically fed into simulation models. Anchoring simulation models into operational hospital information systems prevent facility from many problems that the traditional simulation models have (assuming a lack of support for data or a limited range of data). This will make the simulation model useful for continuous improvement over one aplication. For example, the actual planning that affects the use of resources, will have a dramatic impact on the operating costs, quality of service and effectiveness of health care.

Currently, since as the input data is greatly simplified, the simulation results are often used more for general forecasting and planning than for daily decision-making. The real needs of health systems to lead to lower costs and profits increasements, is the data for decision making support on a daily basis [23]. This is where the desire for efficiency, just simulation prevails over other analytical methods.

1.6.7. Health care processes

Organizational complexity and the flow of patients of a modern health care system are enormous and extensive. Modern hospitals have a large number of interacting units composed of specialized and acute units, third part facilities, external laboratories. This comprehensive cooperation and interaction contributes to a comprehensive intra-organizational workflow and even to a comprehensive model. The challenge of simulation model is to capture the complexity of the organizational flow in a systematic and manageable way. Models should comply with certain characteristics such as hierarchical representation [24], more views etc. On one hand, simulation models should be the tool for process representation. On the other hand, they should also be a simple way of communication and understanding between the third parties and the sources of knowledge [25].

Verification and validation

The real bogeyman of the simulation is a verification and validation that are the subject of extensive research. Without a thorough verification and validation it would be risky, if not disastrous, to make any decisions or forecasts based on model results. One of the new approaches to facilitate the verification of the model is the emerging approach – collaborative, participatory, interactive modeling [6] or CPI modeling, where models are designed together with the participation of medical staff and hospital management [10]. But validation is a completely different problem. The development of a valid simulation model, designing of valid experiments based on the model and perform detailed analyzes of the experiments has resulted in significant research**.**

1.6.8. Conceptual modeling

The simulation model is created and based on the understanding of a fact or the management of a limited space. This is captured in conceptual models that are used as a pattern for the simulation model development and validation of the simulation model from the conceptual model. However, the conceptual approach or model that is the problem domain between the simulation model is largely overlooked. Very little attention has been paid to the research about conceptual medical model. Conceptual modeling as a prerequisite for success in the simulation health care is an area for deeper research.

2. CASE STUDY NO. 1

Aim: Measure the utilization of medical staff in the ward

In the inpatient medical ward work at 1 shift medical staff composed of – 1 nurse, 1 medical assistant. Hospital management wanted to map the current state of this department – staff utilization. Simulation run length was 24 hours. Based on the daily schedule and duration of each treatment and activity that staff have to undertake, we have create and design simulation model in the software SIMIO [26].

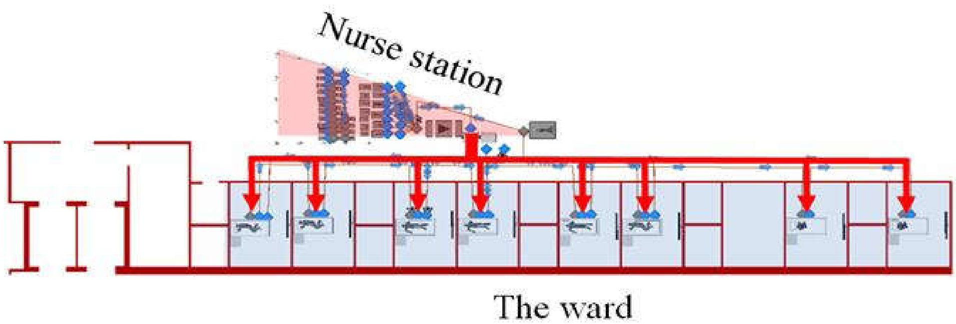


Fig 6. Layout of the ward

2.1. Variant no. 1

Firstly, we wanted to map the current state of the ward in which we considered the following staffing – 1 nurse, 1 medical assistant (MA), 1 practicioner. After a simulated 24 hours, we received the following results.

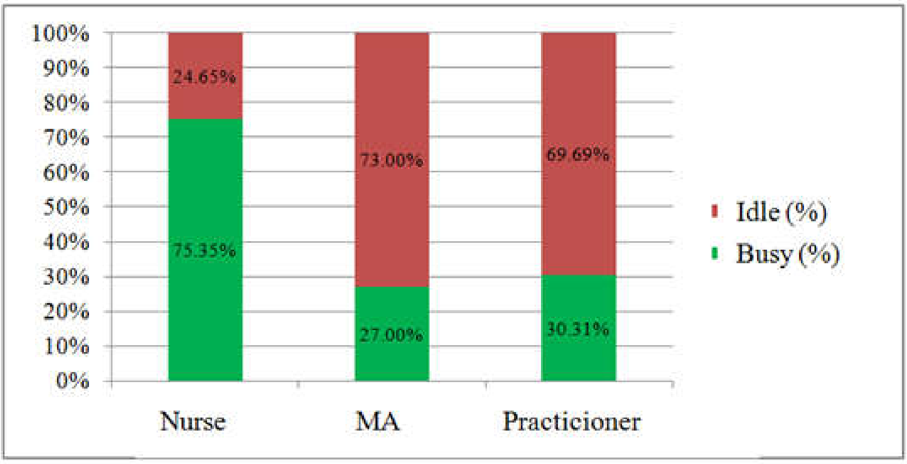


Fig 7. Staff utilization of variant no.1

Workload analysis showed that the individual values are within acceptable limits. However, we found that the time duration of individual performances meant that the staff was able to make only 27.27 % of all daily prescribed exercises.

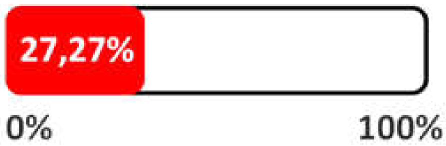


Fig 8. Percentage of completion

2.2. Variant no. 2

Based on the results of variant no.1 we decided to add 1 nurse. This means that in this case we consider following staffing – 2 nurses, 1 medical assistant (MA), 1 practicioner. The results of simulation runs were as follows:

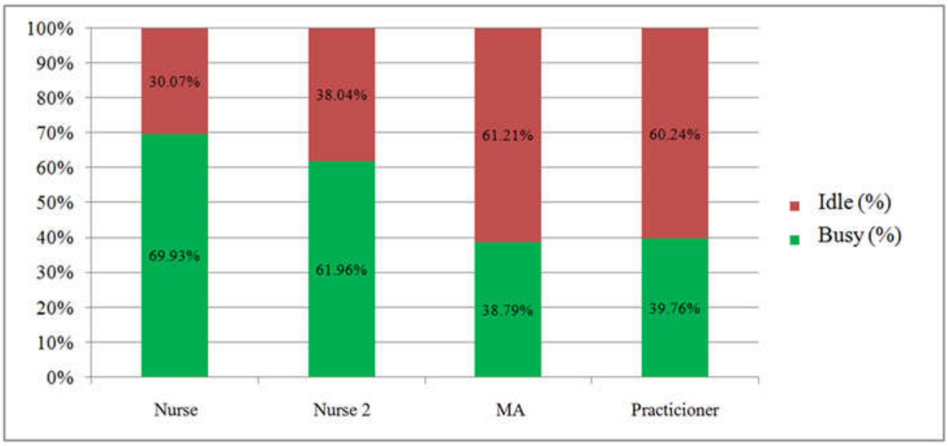


Fig 9. Staff utilization of variant no.2

After adding the second nurse, the utiliz ation of the first one decreased. Both nurses are now running at almost the same level. Adding nurse had also a positive impact on the remaining personnel (medical assistant (MA) and practicioner), because their utilization has increased to a better level compared to the no.1 variant. The most important improvement, however, was the value of the percentage of activities completion. This indicator improved to 86.36 %. However, we still have not reached the state in which all scheduled performances per day are done.

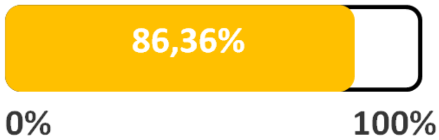


Fig 10. Percentage of completion

2.3. Variant no.3

In this last variant we've tried to add even a third sister. Thus, staffing was – 3 nurses, 1 medical assistant (MA), 1 practicioner. Simulation results were as follows:

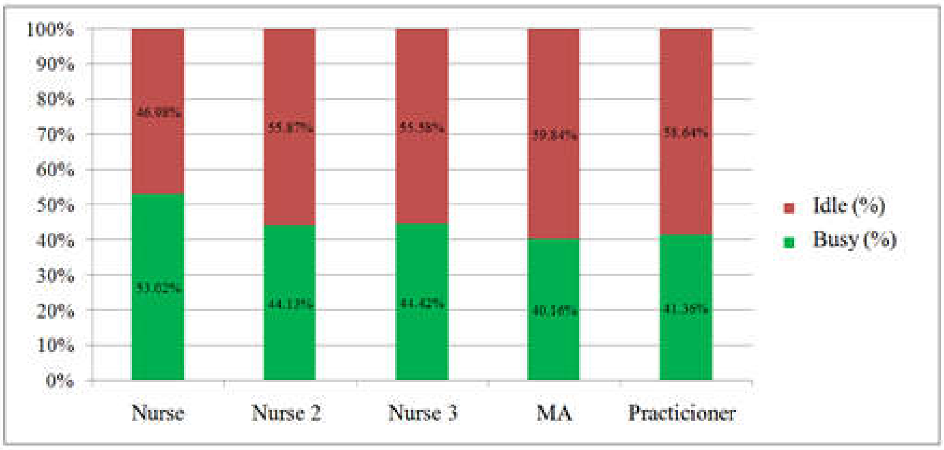


Fig 11. Staff utilization of variant no. 3

After the addition of a third sister occurred two positive effects. Utilization of workers was acceptably reduced and almost got on one level (even utilization of the entire staff) (Fig 11). In such a composition the staff has to be able to fulfill all activities in 24 hours, so the percentage of completion finally reached 100 %.

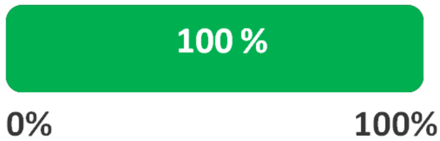


Fig 12. Percentage of completion

2.4. Summary of results

Using simulation, we were able to map the staff utilization on the ward. But we also found out that, at the expected composition of (1 + 1 + 1) the medical staff is not able to perform all the required procedures that are scheduled daily. But with additional staff we have fixed this issue. Additional staff need not to be seen as a source of additional personnel costs. The simulation results showed that additional staff is not only able to manage all of the required procedures, but with increasement of its number we achieve a balanced utilization of all the staff in the department. The detailed results of each variant can be found in the following table 2 and chart [26].

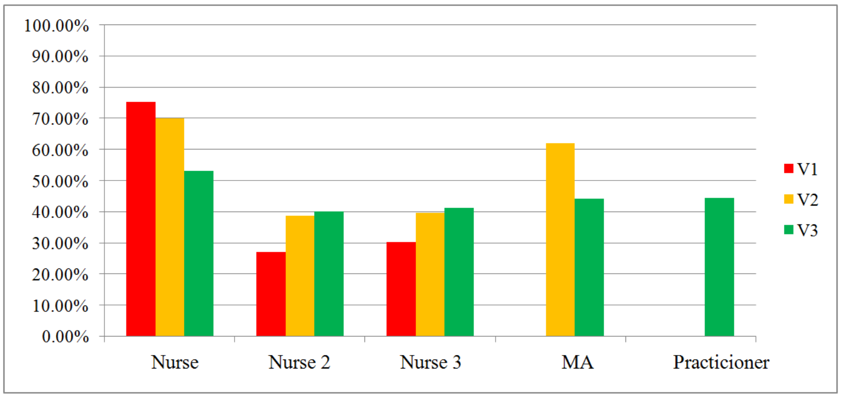


Fig 13. Staff utilization of each variant

Tab 2. Detailed results of each variant

<table>
<tr><th>Staff</th><th>Indicators</th><th>Variant 1</th><th>Variant 2</th><th>Variant 3</th></tr>
<tr><td rowspan="4">Nurse1</td><td>Busy (%)</td><td>65,43</td><td>61,13</td><td>50,43</td></tr>
<tr><td>Idle (%)</td><td>24,65</td><td>30,07</td><td>46,98</td></tr>
<tr><td>Transport (%)</td><td>9,92</td><td>8,80</td><td>2,59</td></tr>
<tr><td>Utilization (%)</td><td>75,35</td><td>69,93</td><td>53,02</td></tr>
<tr><td rowspan="4">Nurse 2</td><td>Busy (%)</td><td>-</td><td>50,85</td><td>39,91</td></tr>
<tr><td>Idle (%)</td><td>-</td><td>38,04</td><td>55,87</td></tr>
<tr><td>Transport (%)</td><td>-</td><td>11,11</td><td>4,22</td></tr>
<tr><td>Utilization (%)</td><td>-</td><td>61,96</td><td>44,13</td></tr>
<tr><td rowspan="4">Nurse 3</td><td>Busy (%)</td><td>-</td><td>-</td><td>39,87</td></tr>
<tr><td>Idle (%)</td><td>-</td><td>-</td><td>55,58</td></tr>
<tr><td>Transport (%)</td><td>-</td><td>-</td><td>4,55</td></tr>
<tr><td>Utilization (%)</td><td>-</td><td>-</td><td>44,42</td></tr>
<tr><td rowspan="3">Medical assistant</td><td>Busy (%)</td><td>27,00</td><td>38,79</td><td>40,16</td></tr>
<tr><td>Idle (%)</td><td rowspan="2">73,00</td><td rowspan="2">61,21</td><td rowspan="2">59,84</td></tr>
<tr><td>Transport (%)</td></tr>
<tr><td rowspan="3">Practitioner</td><td>Busy (%)</td><td>30,31</td><td>39,76</td><td>41,36</td></tr>
<tr><td>Idle (%)</td><td rowspan="2">69,69</td><td rowspan="2">60,24</td><td rowspan="2">58,64</td></tr>
<tr><td>Transport (%)</td></tr>
<tr><td colspan="2">Percentage of completion</td><td>27.27 %</td><td>86.36 %</td><td>100.00 %</td></tr>
</table>

2.5. Conclusion

The key issue for the success of simulation studies of health care is careful formulation of the problem and the involvement of all stakeholders. It should be noted that the simulation of production systems can model data errors that lead to unexpected costs and poor performance. In health care, such errors can lead to loss of patients life. It is therefore not acceptable any space for errors in the design and application of medical simulation models. These limitations can be overcome only with the highest attention to detail and accuracy, as well as communication among all stakeholders. [26] In terms of improving health care systems we want to continue in using simulation and we want to focus on following areas: logistics [27], process quality, scheduling and planning, layout solutions, decision making, time reduction, storage and supply.

3. CASE STUDY NO.2

Emergency department (ED) is located at the University Hospital in Zilina and provides urgent medical care 24/7. Department has 3 rooms: internal medicine room, surgery room, traumatology room. During one shift, there are 3 doctors, 3 nurses and 2-3 medical assistants on ED. Medical staff is working on two shifts (7: 00 a.m. – 3: 30 p.m., 3:30 p.m. – 7: 00 a.m.) during the weekdays and 24 hour shifts during the weekend.

Department is visited by approximately 19,400 patients per year. Patients are initially classified and triaged by their level of acuity by 1-5 ESI index (Emergency Severity Index).

The main problems [28]:

- Overcrowding, caused by non-urgent patients.
- Long waiting times.
- High rate of LOS.

The ED patient flow

Doctors use standardized work and algorithms, for patients treatment. The treatment process in ED at University Hospital in Zilina consists of following steps [26]:

1. Arrival.
2. Triage.
3. Assessment (clinician).
4. The initial diagnosis and treatment.
5. Diagnostic Testing – radiology and biochemistry.
6. Evaluation of the results by doctor.
7. Discharge or admission.
8. Access to a hospital bed and admission by doctor.

3.1. Analysis of input data

In 2013, the ED was visited by 19,443 patients. Detailed analysis of patient arrival rates during year, months, days and hours are shown in Fig 14 and Fig 15.

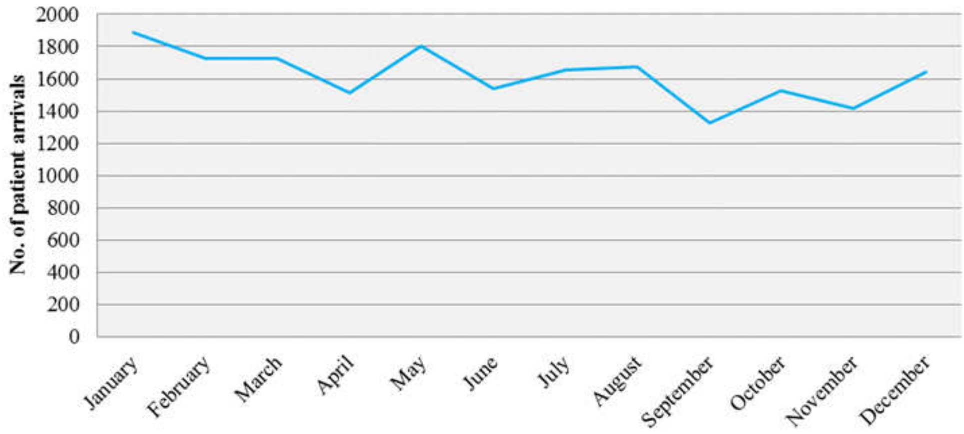


Fig 14. Number of patient arrivals during months

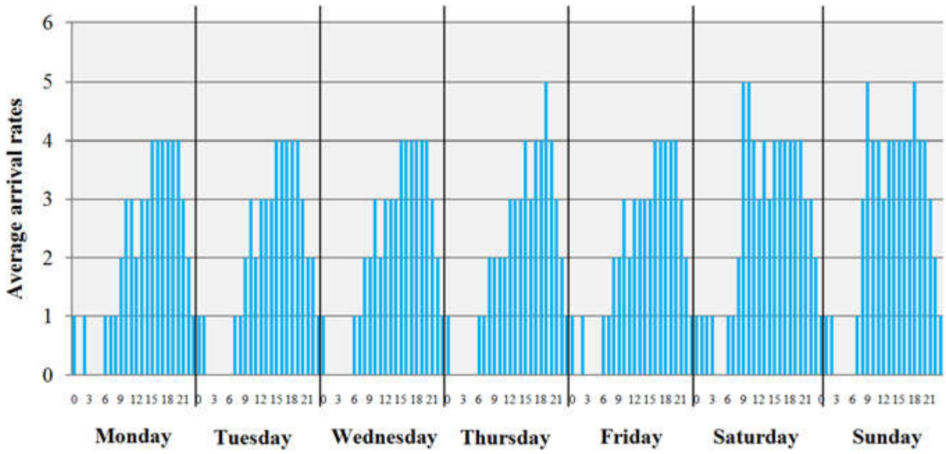


Fig 15. Average number of patient arrivals during daily hours of the week

We defined the arrival rates from the average daily arrival rates during the week (Tab 3).

Tab 3. Patient average arrival rates

Hour interval		Average patient arrivals						
Start	End	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
0	1	1	1	1	1	1	1	1
1	2	0	1	0	0	0	1	1
2	3	1	0	0	0	1	1	1
3	4	0	0	0	0	0	1	0
4	5	0	0	0	0	0	0	0
5	6	0	0	0	0	0	0	0
6	7	1	0	1	1	1	1	0
7	8	1	1	1	1	1	1	1
8	9	1	1	2	2	2	2	3
9	10	2	2	2	2	2	5	5
10	11	3	3	3	2	3	5	4
11	12	3	2	2	2	2	4	4
12	13	2	3	3	3	3	3	3
13	14	3	3	3	3	3	4	4
14	15	3	3	3	3	3	3	4
15	16	4	4	4	4	3	4	4
16	17	4	4	4	3	4	4	4
17	18	4	4	4	4	4	4	4
18	19	4	4	4	4	4	4	5
19	20	4	4	4	5	4	4	4
20	21	4	3	4	4	4	4	4
21	22	3	2	3	3	3	3	3
22	23	2	2	2	2	2	3	2
23	0	1	1	1	1	1	2	1

The composition and numbers of patients treated on ED are shown in Tab 4 and Tab 5. Patients arrive in ED irregularly in a given Mix, as shown in Tab 3. Patients are then classified by their acuity level, with the highest priority of acute patients and the lowest priority of the non-urgent [26].

Tab 4. Patient acuity percentage structure

Type of patient	No. of patients in 2013	Mix	Priority
Non-urgent	6970	36	1
Urgent	9659	50	2
Acute	2814	14	3
Sum	19443	100	-

After triage is made, patients are divided according to their diagnosis into trauma, surgical and internal patient. Percentage structure is shown in Tab 5.

Tab 5. Patient diagnosis percentage structure

	No. of patients in 2013	Percentage
Trauma	7113	36.6%
Surgical	3827	19.7%
Internal	8503	43.7%
Sum	19443	100.0%

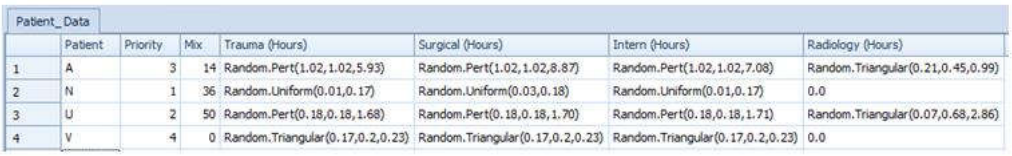
After the triage, patients continue to one of ED rooms and then to external workplaces – Radiology and biochemistry. The duration of treatment at each workplace is shown in Tab 6.

Tab 6. Treatment processing time

		Type of patient		
		Acute	Urgent	Non-Urgent
Room	Trauma	Pert (1.02, 1.02, 5.93)	Pert (0.18, 0.18, 1.68)	Uniform (0.01, 0.17)
	Surgical	Pert (1.02, 1.02, 8.87)	Pert (0.18, 0.18, 1.70)	Uniform (0.03, 0.18)
	Internal	Pert (1.02, 1.02, 7.08)	Pert (0.18, 0.18, 1.71)	Uniform (0.01, 0.17)
	Radiology	Triangular (0.21,0.45,0.99)	Triangular (0.07,0.68,2.86)	-
	Biochemistry	Triangular (0.02,0.03,0.05)		-

3.2. Model settings

In this DataTable we set and assigned the Priority, Mix and treatment ProcessingTime of arriving entities (patients) at each workplace.



Patient_Data

	Patient	Priority	Mix	Trauma (Hours)	Surgical (Hours)	Intern (Hours)	Radiology (Hours)
1	A	3	14	Random.Pert(1.02,1.02,5.93)	Random.Pert(1.02,1.02,8.87)	Random.Pert(1.02,1.02,7.08)	Random.Triangular(0.21,0.45,0.99)
2	N	1	36	Random.Uniform(0.01,0.17)	Random.Uniform(0.03,0.18)	Random.Uniform(0.01,0.17)	0.0
3	U	2	50	Random.Pert(0.18,0.18,1.68)	Random.Pert(0.18,0.18,1.70)	Random.Pert(0.18,0.18,1.71)	Random.Triangular(0.07,0.68,2.86)
4	V	4	0	Random.Triangular(0.17,0.2,0.23)	Random.Triangular(0.17,0.2,0.23)	Random.Triangular(0.17,0.2,0.23)	0.0

Fig 16. Processing time settings

We set patients ArrivalRates by Rate Table (Fig 17), in which we assigned average patient arrival rates for each hour interval of the day (7 days). Triage process and patients result obtaining process we set by Processes that are shown in Fig 17.

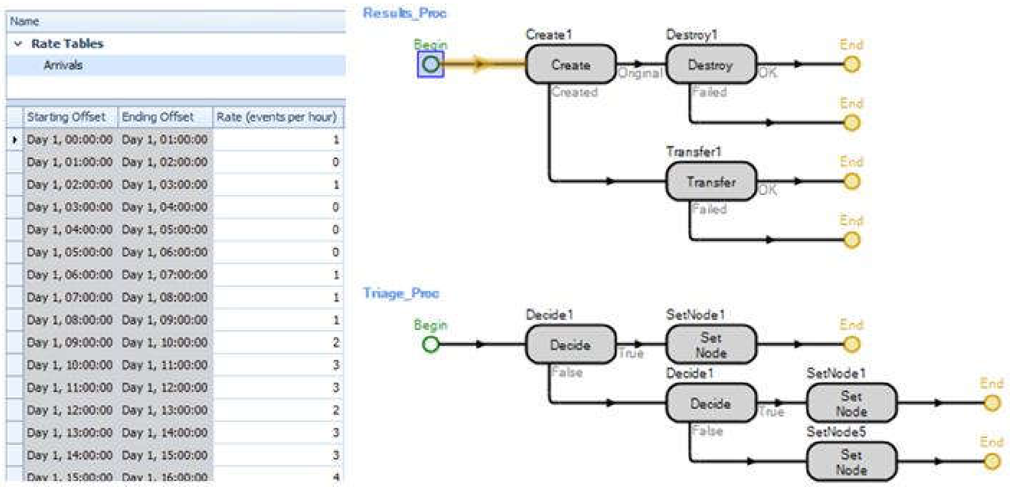
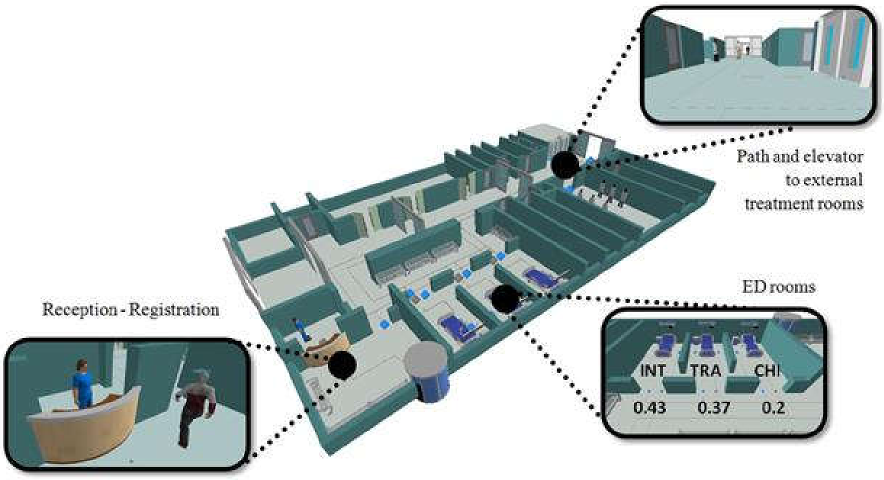


Fig 17. Model logic processes settings

3.3. Simulation model - Current state

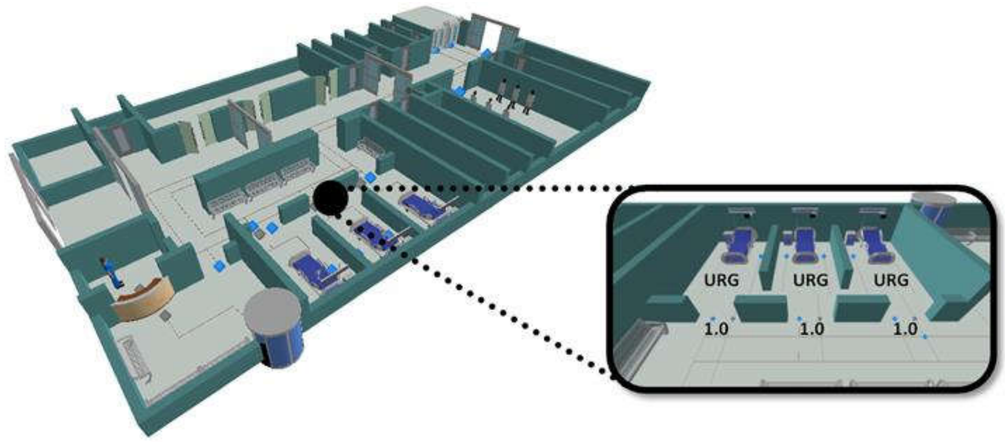


3.4. Simulated variants

The length of simulation run we set to 7 days (1 week) and we simulated current state and 3 improvements. The detailed description of each improvement can be found in following chapter.

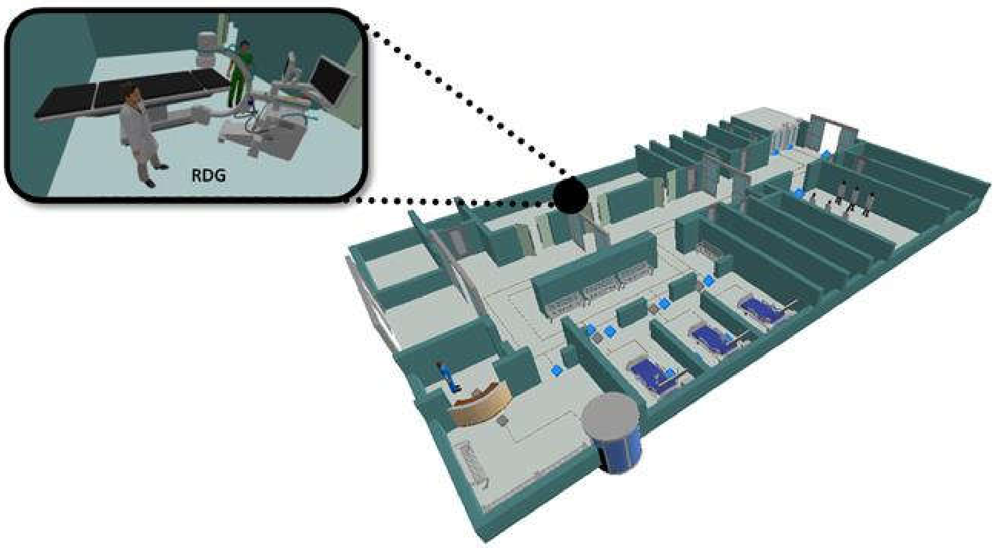
3.4.1. Improvement no. 1

Transformation of 3 specialized ED rooms into 3 equivalent urgent rooms. So the patients can be treated at any free room.



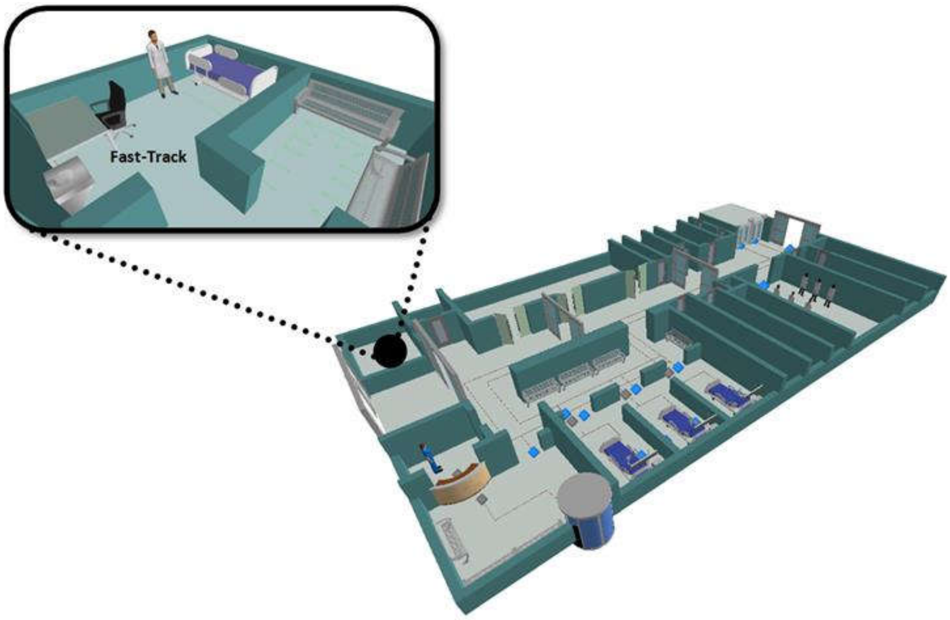
3.4.2. Improvement no. 2

Creating Radiology room in ED (C-arm). So the patients do not have to go to external workplace. They can be scanned on ED. (necessary additional personal resources: radiologist and nurse)



3.4.3. Improvement no. 3

Implementation of Fast-track. With this improvement, it would be possible to find out (by quick set of tests) if a given patient need to be treated in ED. ED will be then able to recognize non-urgent patients. These patients would be send home or to another hospital department, so ED will not be overcrowded in such rates. (necessary: triage doctor / nurse).



3.5. Comparison of improvements

After the simulation, we got the results that are shown in Tab 7, Tab 8 and in charts. In the results we focused on these indicators:

- LOS (average).
- Utilization of ED rooms (%).

Tab 7. Average LOS in ED (hours)

	Average LOS			
Patient Type	Current state	Improvement no.1 (URG)	Improvement no.2 (RAD)	Improvement no.3 (FT)
Acute	4.06	4.2	3.76	2.33
Urgent	28.92	14.21	9.17	2.83
Non-urgent	1.64	0.93	1.77	2.26

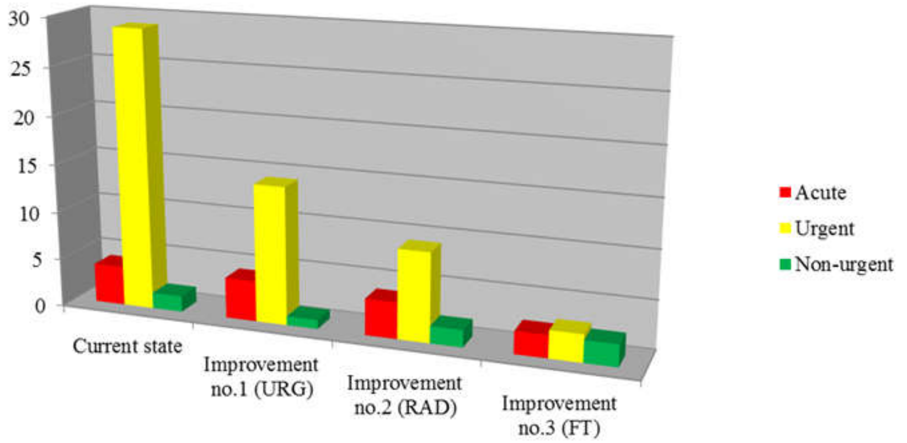


Fig 18. Average length of stay of each type of patient in ED

Despite the fact that the improvements were done only on one isolated departments (not in whole facility), we were able to eliminate steps that do not add value for patients. [29]

Tab 8. Utilization of ED rooms

	Utilization			
ED Room	**Current state**	**Improvement no.1 (URG)**	**Improvement no.2 (RAD)**	**Improvement no.3 (FT)**
Trauma	46.59%	48.42%	42.46%	24.45%
Surgical	37.19%	38.26%	31.23%	20.98%
Intern	52.96%	39.78%	46.44%	35.34%

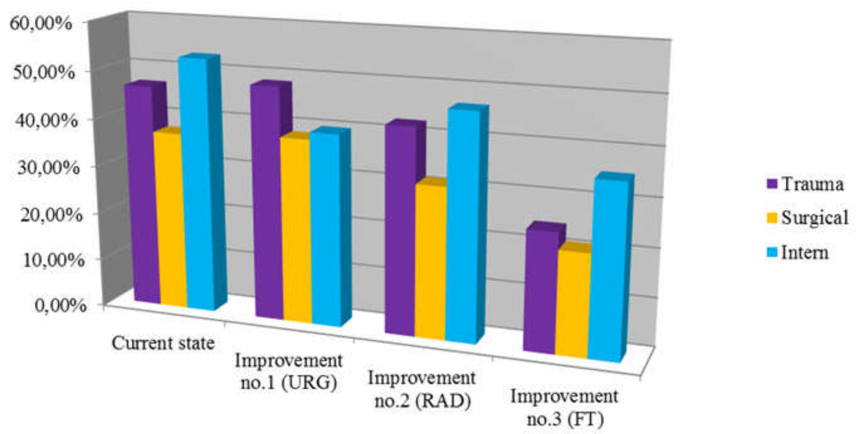


Fig 19. Utilization of ED rooms in each improvement

3.6. Results

From simulated variants we found out, that overcrowding and LOS in ED are directly caused by number of non-urgent patients and by length of treatment on external workplaces. First indicator, we were focusing on, was average LOS. When we look at the results, we can see that improvement that most reduced the average LOS, was the implementation of Fast Track. This improvement is not only reducing LOS but is also aligning LOS for each type of patient. The creation of Radiology room had also an positive impact on LOS but in lower rate. The second followed indicator was the utilization rate of ED rooms. The utilization rates, in comparison with the current state, were most reduced by Fast Track implementation. It means, that this improvement had double effect: Firstly, we were able to eliminate non-urgent patients from ED. Secondly, we managed to reduce the average LOS on ED. [26]

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