Review Article

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A Step-by-Step Framework on Discrete Events Simulation in Emergency Department; A Systematic Review

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ABSTRACT

Objective: To systematically review the current literature of simulation in healthcare including the structured steps in the emergency healthcare sector by proposing a framework for simulation in the emergency department.
Methods: For the purpose of collecting the data, PubMed and ACM databases were used between the years 2003 and 2013. The inclusion criteria were to select English-written articles available in full text with the closest objectives from among a total of 54 articles retrieved from the databases. Subsequently, 11 articles were selected for further analysis.
Results: The studies focused on the reduction of waiting time and patient stay, optimization of resources allocation, creation of crisis and maximum demand scenarios, identification of overcrowding bottlenecks, investigation of the impact of other systems on the existing system, and improvement of the system operations and functions. Subsequently, 10 simulation steps were derived from the relevant studies after an expert's evaluation.
Conclusion: The 10-steps approach proposed on the basis of the selected studies provides simulation and planning specialists with a structured method for both analyzing problems and choosing best-case scenarios. Moreover, following this framework systematically enables the development of design processes as well as software implementation of simulation problems.

Keywords: Emergencies; Computer simulation; Critical care; Electronics.

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Introduction

The use of simulation method to problem solving has become popular since the introduction of the computers. Computer simulation models compress real time intervals to short episodes and can be used to investigate complex systems that would otherwise be hard to study. These models mirrored the effect of changes without real physical changes. Dangerous situation in real life can be modeled without any risk. Controlled experiments with varying parameters are a very important advantage of simulation [1]. Perform process analysis is a very costly approach because it requires active

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participation of stakeholders. Simulation visualize and evaluate conceptual models about observed process behavior and helps in analysis, forecasting and decision support [2]. Several methods had been introduced in simulation context. To model and study of a discrete event dynamical system, discrete-event simulation method was applied in various fields [3].

Discrete simulation approach efficiently manages to assess various operational scenarios. With regard to emergency departments, the approach helps to propose innovative plans and design new departments. Hospital administrators need to be directly involved in creating these projects so that they can more willingly accept the simulation processes in healthcare systems. Moreover, simulation processes should be simplified to the extent that they preserve their functionality, and visual and animation tools should also be used so that users better rely on the model capabilities [4].

Health care costs have risen sharply over the past several decades. This is while health care organizations have been pressured to improve the quality of care for patients. In this regard, a great number of managers have made use of discrete event simulation as an effective tool for allocating limited resources to improve management of patient movement and minimize the cost of healthcare provision, as well as to increase patient satisfaction. The rapid growth of simulation software technologies along with complex implementations combined with optimization has led to many practical, efficient advances and developments [5].

The emergency medicine globally concerns the increased number of patients and workload in emergency department and has a high workload specially in operating rooms [6]. Proper estimate of the employed resources and patient flow in emergency departments is vital in determining aspects of the activity which can lead to improved procedure, reduced wait time and increased efficiency of employees and their motivation [7].The excess wait time is an important issue in emergency services which negatively affects the quality of health care. However, this issue can be resolved by improving services through discrete event modeling and simulation of the system process. Studies on the simulation of medical systems demonstrate key areas for quantitative evaluation of the strength of existing systems against incidents and events that may occur in the future [8].

Emergency departments is one of most critical wards of hospitals with a high proportion of admission in Iran [9]. Emergency department managers are now dealing with the issue of efficient allocation and utilization of human resources. Increasing pressure on the part of rivals, care reform, problems with repayment and increased care costs are important issues that overshadow other issues [10]. On the other hand, the quality in each hospital is associated with the performance of its emergency department. Several studies have been carried out in this regard with the aim of increasing the efficiency of this department using simulation tools. Many of these studies have attempted to reduce wait time and also, increase level and throughput of services by improving the process or promoting the size of emergency operations [11].Simulation of discrete events has turned into a popular tool for healthcare decision makers in order to achieve the stated objectives. achieved information can help healthcare managers and analysts to identify alternative management scenarios which can be used to reconfigure the existing systems in order to improve system performance or design and plan new healthcare systems without changing the existing ones [12].

Based on the literature reviewed here highlighting the significance of simulation in healthcare, this study has taken promising structured steps in the emergency healthcare sector by proposing a framework for simulation in the emergency department.

Materials and Methods

The method of current study includes two phases. At first a survey on related papers was conducted in form of qualitative review. In second phase, an online focus group discussion was performed on proposed model, then model was adapted based on expert's recommendations and weakness points were solved. Details of two mentioned phases were described as follow:

Phase 1: Review

Based on previous studies and significance of simulation in healthcare, this study intends to propose a comprehensive framework for simulation in the emergency department and provide instances in this regard and thus, takes considerable steps towards developing the simulation processes. This qualitative review study was conducted in 2014. Proposed simulation framework has a general strategy in modeling of healthcare systems.

The keywords in the query was "((Emergency department) AND discrete event simulation) AND ("2003"[Date - Publication]: "2013"[Date - Publication]))". PubMed and ACM were searched in a ten years period from 2003 to 2013. Inclusion and exclusion criteria: study limited to a custom range from 2003 to 2013. Only periodical journal papers have been included in search. Articles not available in full text through the university Access network were excluded from the study. Only English manuscripts were added to results. In first round, title and abstracts were studied and unrelated papers to research scope were excluded. All records imported to Endnote software and Duplicate records were removed. In second round the qualified full text studies were separately analyzed by four researchers

using the data extraction form, developed based on the objective, which contained data elements about the study, year, objectives, methods, solutions, results and findings based on simulation methodology steps. In the process of data extraction, any disagreement between the researchers was unanimously resolved and unrelated papers were excluded. Figure 1 shows the detailed trial flow of review.

Phase 2: Focus group discussion

Designed model was shared by eight experts in two sessions in form of focus group. Experts consist of three health informatics, three industrial engineer, and two emergency medicine experts. According to references, a well formed focus group needs six to ten persons for each meeting [13]. In current study, Convenience sampling method was applied. Image of model was sent to online group in a certain time. Every session take a time about 60 minutes.

Positive and negative characteristics of model were discussed, and then these attributes were ranked based on importance by session conductor. Because of the objective of these sessions was to make a fundamental structural and conceptual understanding from model, first session conducted in unstructured form. Second session has a certain theme. Second session includes tasks such as identifying process sequence or concurrency, importance of steps, and selection of steps. Collected data from sessions were coded by researcher based on their importance factors includes frequency and mention first factor. Finally model improved based on agreed sequence, concurrency, select or deselect of steps, and importance of it in a qualitative manner. To representation of model, we used Unified Modeling Language (UML) activity diagram as a common and standard language in software process modeling according to agreed criteria's. The outcome of the focus group discussion presented as an activity diagram which was modeled by an experienced software engineer.

Results

Figure 1 presents result of review phase and flow of selection of related studies. Finally 11 studies included in review process. Table 1 describes the selected studies and their results. As can be seen in the table, a technical approach is used for the extraction of the elements. The objectives of the studies selected in this research can be summarized to a number of factors including reduction of wait time and patient

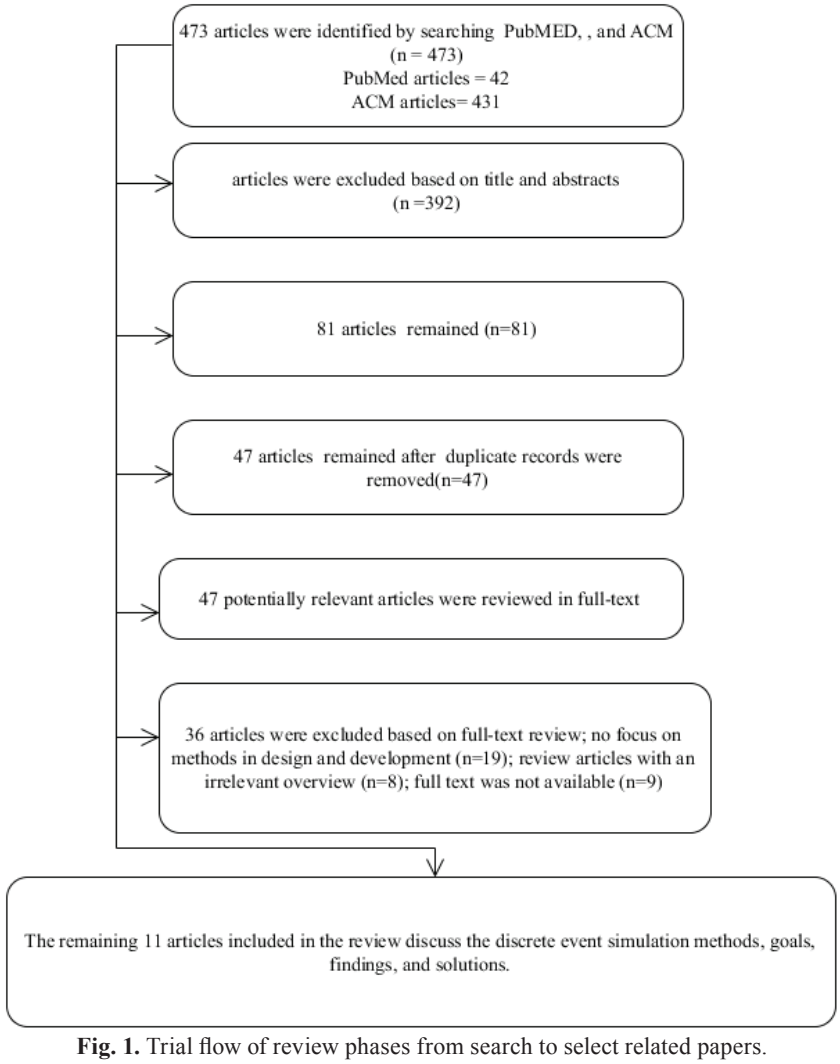

Fig. 1. Trial flow of review phases from search to select related papers.

Table 1. A comprehensive view of selected studies with goals, method, solutions, and finding columns

No	Title	Year	Goals	Methods	Solutions	Findings
1	Modelling and simulation of emergency services with ARIS and Arena. Case study: the emergency department of Saint Joseph and Saint Luc Hospital [14]	2009	• Simulating patient visit process to reduce waiting time • Identifying bottlenecks and specifying resources and humans without system failure or crash	• Arena & ARIS	• Some solutions to empower physicians and improve their performance • Applying quick pass process	• Summarization of observed opportunities and weak points were modeled in software environment.
2	Computer Modeling of Patient Flow in a Pediatric Emergency Department Using Discrete Event Simulation[7]	2007	• Simulating patient flow in pediatrics emergency department	• ARENA • 517 patients were observed and all aspects of interactions were registered • Patient demographic information combined with flow to model patient input rate then was used in patient scheduling • Scenario was applied and output performance was evaluated.	• The model displayed patient flow accurately and various scenarios were near to reality • Changes on model effects on patient flow effectively	• Evaluation was performed in model wide and process-specified levels • Simulation on selected hospital and adding second triage nurse showed decrease of waiting time • An additional medical shift leads to decrease of patient length of stay in all categories.
3	Emergency departments I: the use of simulation to reduce the length of stay in an emergency department[15]	2003	• Assessment of existing operations and evaluating alternatives to reduce length of stay	• Data was collected in 7/24 • All performed operations in ED were evaluated	• Modeling system without patients stay in wards • Presents educational aspects of ED on length of stay • personnel's levels Change impact on length of stay	• Findings shows that simulation significantly leads to time and cost saving in hospital
4	Emergency departments I: the use of simulation and design of experiments for estimating maximum capacity in an emergency room[16]	2003	• Estimating maximum time of requests in ED or hospitals	• Creation of studied system simulation model • Creation of time variable behavior in system based on model • Estimation of maximum capability of responses by system • Design a test to identify minimum needed physicians and resources to requests administration	• Developing a simulation model to generate a patient waiting time prediction curve and estimating maximum number of requests	• Findings shows that needed resource to this level of requests was very near to highest level.
5	Improvement of Waiting Time for Patients Referring to Emergency Room Using Discrete Event Simulation[17]	2011	• Reduction of patients waiting time • Timing of services in ED • Modeling and improvement of service timing • Identifying bottlenecks	• Collecting information through observation and questionnaire • Arena software • Modeling of five various scenarios • In a one year period • Applying a workflow timing checklist in ED services	• Execution of triage process in ED and usage of emergency experts in earlier levels and apply a lab expert to make faster reporting of results can solve the problem	• The maximum waiting time from test request to report results was taken by physician visit time • Adding three more personnel's improve triage process

No	Title	Year	Goals	Methods	Solutions	Findings
6	Healthcare process analysis: the use of simulation to evaluate hospital operations between the emergency department and a medical telemetry unit [18]	2003	• The ability of view procedures and performance in ED ward and medical telemetry as well as impact of procedures of each ward on others • To help in self-performance assessment and creation of visions in some areas to improvement. • Identifying and measuring bottlenecks • Clarification of interoperability between ED and telemedicine wards	• Collecting information through a primary interview with ED personnel's ,medical telemetry, housekeeping, bed control, registration as well as the director of Patient Care Operations • In a two days period	• Creation of a simulation model for current system to evaluate current state of length of stay in ED and improvement of operations	• By applying simulation in hospitals to achieve same results, three of ten changes can lead to a satisfying results
7	A simulation study to achieve healthcare service quality improvement in accident & emergency department (AED)[8]	2011	• Quality improvement of medical emergency services by improvement of operations performance	• Simulation and focus on predicted visit time missing causes • Designing of data collection system	• Creation of an accurate model to facilitate decision making in clinical workflow, facilitate resource allocation, capacity programming, evaluate treatment efficiency and process re-engineering.	• Facilitated workflow decision making • Assessment of possible innovative solutions
8	Simulating patient flow through an Emergency Department using process-driven discrete event simulation[10]	2009	• Improvement of patient flow by a novel architecture	• Explanation of architecture and presentation of resource applying to improve effectiveness in hospital EDs	• Create a flexible architecture in ED facilitate the ward administration	• Primary results shows that suggested architecture significantly facilitate accessibility and flexibility to run a wider range of simulation models. • Running of various approaches leads to improvement of EDs
9	Understanding Accident and Emergency Department Performance using Simulation[19]	2006	• Help in understanding of effective factors in personnel's related operational objectives	• Using of real data in patient admission system in ED center and analysis of them • Focus on multi-tasking behavior and experience of care personnel's which impact on performance	• Identifying and setting of test scenarios and evaluate models displayed that experienced physicians, increase of X ray process time and decrease its intensity	• Effectiveness of medical personnel's experience an multitasking behaviors in overall performance of hospital

No	Title	Year	Goals	Methods	Solutions	Findings
10	Modeling and Improving Emergency Department Systems using Discrete Event Simulation[11]	2007	• Reducing patient waiting times • Improving overall service providing and system throughput	• Applying various scenario based on resource management to evaluate waiting time • What-if analysis was performed	• Findings shows waiting time from admission to access visiting room was most challenging problem. • Adding a physician and a nurse improve waiting time • Developed approach is beneficial to other health systems	• Shorter waiting times leads to improvement of service level • Adding of assessment room has no effect on performance • Cleaning cost added to assessment room costs.
11	Forecasting Emergency Department Crowding: A Discrete Event Simulation[20]	2007	• To prediction of future operational states and assessment of these predictions	• Evidence-based • A theoretical model • Six variables were included in input and output • The model predicates no of waiting, waiting time, occupation area, duration of length of stay, no of stay nights and ambulance derivation • Performance was calculated using Pierson coefficient • ROC was plotted.	• Results shows good correlation between random and real distribution • All measures exception of boarding time, which has natural bias, modeled accurately • Congestion modeling and prediction of its outcome was one of the most important parameters • All parameters could be extracted from patient data, directly.	• By modeling of patient flow, some measures in near future about congestion and various degree of performance were calculated

stay, optimization of resources allocation, creation of crisis and maximum demand scenarios, identification of overcrowding bottlenecks, investigation of the impact of other systems on the existing system, and improvement of the system operations and functions as well as prediction of its future status. Moreover, the results also revealed that the Arena simulation software was mostly implemented in the selected studies among other simulation software. The outcomes and results obtained from the studies are detailed in the Table 1 .

Discussion

Presenting a Model for the Simulation Steps

According to the step-by-step simulation processes discussed in aforementioned studies, a comprehensive model was proposed to run a simulation project in the field of medicine (as shown in Figure 2). It should be noted that the steps start after the statement of the problem. Therefore, the problem as well as the field of study and the healthcare environment should first be specified and simulation should also be an approach to predict or improve the system.

The most popular diagram in modeling of software processes is the activity diagram.it is often used in software modeling projects to document program flow such as algorithms or steps to implement a specific action. Experts in related domains to software engineering could simply interprets activity diagrams [21]. The advantage of current model was to use elements such as fork-join because they make it possible for experts to display and understand parallel events which many medical workflows have. The activity diagram models are well suited for the illustration of discrete events, since these events rarely occur in a linear manner and often exhibit parallelisms [22, 23]. We proposed agreed model after focus group discussion, based on activity diagram. Each step was described in following sub-headings.

Step 1: Creating a View of the System (Graphical Plan)

In most studies reviewed, there was a view of the physical structure of the emergency department. This view examines the floor plan of the building two-dimensional architecture. The plan is aimed to provide a full understanding of the system and create an impression in managers and simulation specialists to design more perfect physical entities in the system, including the wards, beds, and waiting rooms. Another important

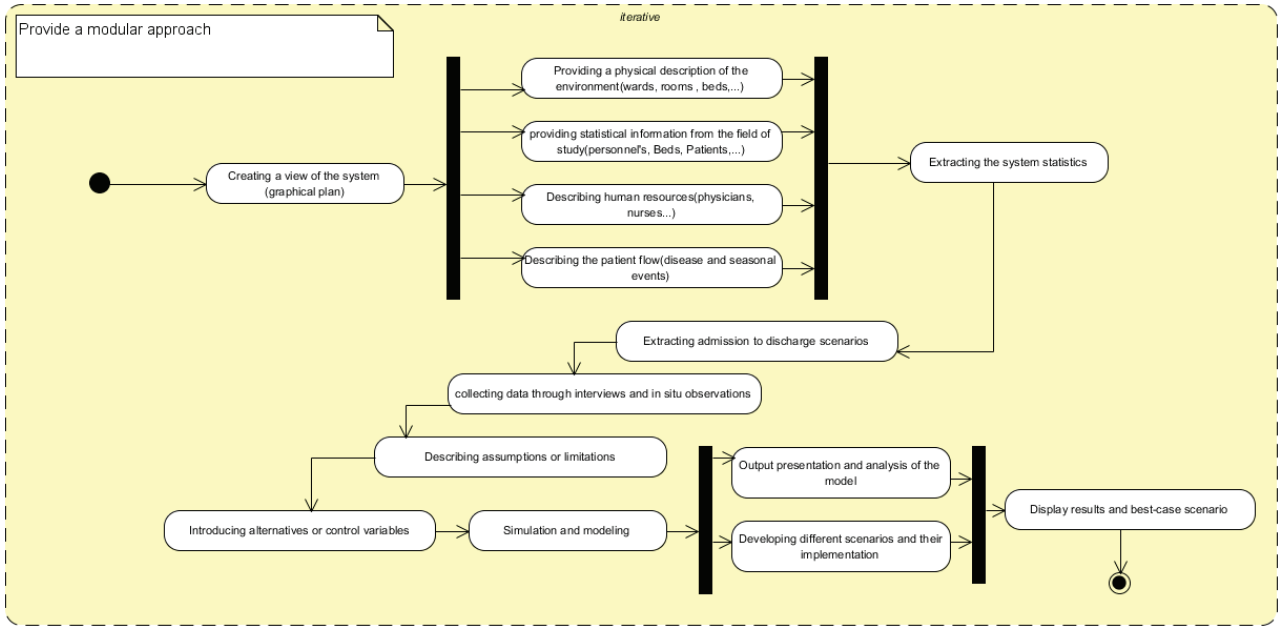

Fig. 2. Proposed model to simulation of medical systems based on discrete events.

application of the plan is in designing animations to simulate. In this case, the designed building in the simulated animation will be in accordance with the actual physical building. The plan possesses the details needed and its scales are not accurate. Other forms of lower frequency were also used to show the structure [24].

Step 2. Data Description and Gathering

2.1 Providing Statistical Information from the Field of Study

Almost all research conducted on the simulation of the healthcare systems have been dealing with some system-related figures and statistics in the introduction section. These statistics can include the number of employees and available or accessible human resources, the facilities available, the figures related to the physical structure of the system such as the environment and area, the number of patients who refer to the hospital periodically, profit or loss and the system rank and quality. This step aims to provide a transparent view of the system volume and diversity for the simulation specialists. It is worth noting that the system volume and physical diversity is not necessarily indicative of its procedural complexity. The statistics are different from those which are provided in the next steps through direct observations or mathematical models [25].

2.2. Providing a Physical Description of the Environment

Like the two previous steps, this step is to further clarify and introduce the system. In this section, various wards and sectors such as care rooms and intensive care units on the floor plan are described. In addition, the structure of the room, its existing facilities, and physical resources consumed or occupied in this room are also mentioned [26].

2.3. Describing Human Resources

According to the research content and methods, this step is also included within the proposed model and framework and is complementary to the previous steps. A qualitative and quantitative estimate of human resources within the system is to be offered [27]. Further, the features and behaviors of these components, including their shifts and scheduled services, can also be expressed. Table 2 shows an example of such an estimate.

2.4.7 Describing the Patient Flow

In this step, happenings and events periodically affecting the system, its physical structure and human resources are mentioned. In the healthcare field, weekends, seasonal events and diseases, occurrence of epidemiological diseases or natural disasters can be stated [7, 28]. This aims to provide temporary and abrupt scenarios for a more detailed understanding of the system. As it was mentioned, the first to fifth steps in simulating a healthcare system are focused on presenting a comprehensive view of the system without having procedural and technical discussions. These steps contribute to a greater recognition of the next steps with higher reliability and credibility. The analysis and design of the simulation project initiate from the sixth step.

Step 3: Extracting the System Statistics

This step system is associated with the current situation. During this step, simulation experts and practitioners involved in the project extract the system resources information within an appropriate period, depending on the ward in which the simulation occurs. This statistics can be extracted through an interview or, if possible, through reporting the IT systems in the research environment. In emergency

Table 2. Mathematical and statistical modeling of flow parameters in simulation research

Resource	Triage nurse	Registrar	Bedside nurse	Assessment	Draw blood	Discharge	Charge nurse	Physician	Treatment (high priority)	Treatment (low priority)	Consultation	Delegate	Treatment (low priority)	Consultation	Beds	Radiology
Capacity	1-4	1-4	1			2	2				1				4	2
Process time (minutes)	15	5		12	5	12			12	6	7		5	5	NA	12
Distribution	Poisson	Lognormal		Beta	Triangular	Triangular			Triangular	Triangular	Triangular		Triangular	Triangular		Beta

systems, statistics such as the number of clients or number of beds and their occupancy rates are concerned [29].

Step 4: Extracting Admission to Discharge Scenarios

In a majority of healthcare systems, the processes initiate with admission and end up with discharge [30]. This step addresses these processes modeling. This step only deals with the process considered by the experts to improve or predict based on the simulation. Flowcharts are often used to display it.

Step 5: Collecting Data through Interviews and in Situ Observations

This step is one of the most time-consuming and most challenging simulation steps. The research considered two approaches in this step. Some research used mathematical and statistical methods and statistical distributions to meet the parameters of the processes available in the flowcharts of the seventh step. Although this approach is simpler, it is of lower reliability. Some research also took advantage of the actual data as the spreadsheet generated by observations, data mining, or intelligent computerized algorithms [31]. Therefore, during a long period through tracking the in situ process, the required information such as patients' time of arrival, wait time, the bed shortage or lack of doctors, the employment rate of the resources or manpower by the patient, and so on are obtained through conducting interviews with health care providers and patients as well as recording and classifying the data. The second approach is better to have a more accurate simulation of a specific environment; however, the first approach is of greater generalizability. In this step, there are data processing and relevant variables for each phase. The outcomes of this step are the parameters of the simulation model [32, 33]. Table 2 and Table 3 represent two samples of statistic and spreadsheet models. Both approaches require to active engagement of policy makers and experts involved in domain of problem. This collaborative methodology (Agile Methodology) led to a collective ownership by the stakeholders and was a important factor in the accurate adoption of the simulation model [34].

Step 6. Describing Assumptions or Limitations

In this step, the assumptions and limitations discussed in the system simulation studies for researchers are modeled. These assumptions are associated with the research objectives. For example, it is assumed that adding 10 beds in the emergency department would improve the wait time. Limitations are also based on the research limitations in addition to the restrictions which cannot be modeled in the simulation environment. For example, the clinical aspects are not supported in simulations.

Step 7. Introducing Alternatives or Control Variables

In this step, some control variables including human resources or service providers are added to the system.

Step 8. Simulation and Modeling

The results of the seven previous steps are implemented at this step through using the software. At this stage, according to the information recorder in the previous steps and despite the limitations of the software, a model is to be implemented close to reality as much as possible. To this end, there is a number of software and the most widely used software in the studies reviewed is the Arena Software [35]. Some newer multi-user virtual reality platforms were used in recent studies to generate 3D models related to staff behaviors in ED. A popular platform is CliniSpace that performs like a game. Each staff can join to

Table 3. Spreadsheet modeling of flow parameters in simulation research

	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
A	Cust	#		start	1	2	3	4	5	6	7	8	9	10	11	12	13
B	Interarival	Time (min)			2	2	1	1	1	3	3	1	1	2	2	3	1
C	Arrival	Time (hr. min)		8:30	8:32	8:34	8:35	8:36	8:37	8:40	8:43	8:44	8:45	8:47	8:49	8:52	8:53
D	Service	Time (min)			2	8	8	8	7	3	4	3	3	2	9	9	5
E	Server Number 1	Start (hr:min)			8:30		8:32		8:40		8:43		8:46	8:48		8:57	9:00
F		End (hr:min)			8:32		8:40		8:47		8:47		8:49	8:50		9:02	9:05
G	Server Number 2	Start (hr:min)				9:02		9:11		9:20		9:26			9:35		9:44
H		End (hr:min)				9:11		9:20		9:26		9:35			9:44		9:50
I	Wait	Time (hr. min)			0:00	0:00	0:01	0:04	0:03	0:02	0:12	0:14	0:18	0:10	0:09	0:06	0:8
J	Total	Time (hr. min)			0:03	0:05	0:05	0:04	0:09	0:10	0:12	0:16	0:20	0:22	0:26	0:25	0:23

virtual environment by selecting a character and outcome of his actions may resulted very different overall outcome of system [36]. Today, simulation, gaming and virtual reality are moving hand in hand in evaluation, education and improvement. Additionally, attention to the application of mixed methods is increasing in recent studies. Morgan *et al.* developed a novel toolkit to support mixing of discrete event simulation and system dynamic methods. They proposed developing of new software to model mixed strategies in single environments.

Step 9. Analysis ant Test

9.1. Output Presentation and Analysis of the Model

When the software implementation of the simulation model ends up, the results are analyzed through running the simulation and obtaining reports from the system and the efficiency of the current system is calculated and determined based on key indicators.

Step 9.2. Developing Different Scenarios and Their Implementation

In this step, various scenarios are designed and implemented based on the requirements in order to examine and analyze the effect of the change in control variables, resources and inputs on the key indicators such as wait time [37]. The scenario refers to different states that can be developed in the system, e.g. increasing the number of nurses in the hospital from 100 to 120 or reducing the number of usable beds from 70 to 50. The results of the various scenarios are recorded as the generated reports.

Step 10. Present the Results and the Best-Case Scenarios

The final output of each scientific project is to increase efficiency and provide optimal results [38]. In the simulation projects after running the designed and existing scenarios, the best-case scenario will be presented as the output to the administrators and customers of the simulation projects in order to enhance the efficiency in the actual system.

Providing a Pervasive Modular Approach

A modular look, or in its more advanced form, object-oriented approach breaks a major problem to smaller ones. Then, the major problem is solved through solving the smaller problems and combining them with a controlled approach [39]. In simulation problems, a major problem such as the hospital can also be divided into one or more problems such as wards. Then, each problem can be solved separately and, the results can ultimately be integrated and generalized. Hence, if the simulation problem in this approach is major in terms of physical and procedural size, it is divided to sub-problems. It is not a formal steps in recommended model. This approach must be extended in whole of model.

Conclusion

In this study, 10 consecutive steps to design and develop issues relevant to the software simulation issues were proposed with an emphasis on medical emergency department. This approach provides the calculation and simulation science professionals with a development cycle in order for them not only to determine the simulation objective but also to adopt a systematic approach in modeling and problem analysis. The findings of this study indicate the usefulness of simulation methods in emergency and other areas of medicine. In addition to the use of the proposed approach in the research, covering the modeling and simulation software of the 10-step approach in the form of documentation and utilizing values is recommended.

Conflict of Interest: None declared.

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