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Simulation modelling in healthcare: Challenges and trends

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Abstract

In this paper, we describe simulation models in healthcare that have been developed in the past two decades. Simulation systems, ranging from simulation of patient flow in emergency rooms to simulation of populations with a specific chronic diseases, are reviewed. Simulation types included discrete event simulation (DES) and agent based simulation (ABS). A trend of variability and scalability were identified, and discussed in terms of platform used to develop the model, data sources, and computational power needed to run the simulation. In the synthesis of simulation models, programming languages and products emerged as clusters. Design models and systems engineering development processes are examined with a focus on requirements discovery, models and scenarios of simulation. Graphic user interfaces in the simulation tools in healthcare are reviewed in terms of visual design and human factors. Furthermore, interaction modes and trends of information visualization techniques used for the simulations are reported. Agent-based simulation models in particular were reviewed, and findings suggest agent characteristics varied across literature researched in aspects such as socio-demographic design considerations.

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Keywords: Simulation; Healthcare; Modelling; Agent-based software engineering

1. Introduction

A proliferation in simulation models in the domain of medical research and management of healthcare services is evident[1]. This growth is driven by the leveraging capability of these simulation models in addressing complex problems that cannot be addressed by decision support systems. Much of its growth can be attributed to recent

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technology development sin computational processing capabilities and the volume of real-time and discrete data available for analytics. Previous studies conducted on simulation modelling in healthcare have mainly focused on staff scheduling, resources allocation and patient waiting-time management. Simulation systems that have been designed and implemented in healthcare were attracting different operational problems such as management of patient flow inside emergency rooms [1][[2], allocation of human resources around the hospital [3][4], patient admission [5], hospital bed utilization [6][7]. It has also expanded to study the epidemiology, and consequently systems were developed to simulate populations with a specific chronic disease [8], or with a particular disease of a network that provides healthcare services [8], or during an epidemic crisis [9].

Simulation modelling in healthcare is an effective approach to understanding the interdependency between human-oriented and infrastructure-oriented variables in complex systems of systems (SoS), and to explore scenarios of decision-making from different stakeholders or practitioners. However, the knowledge that underlies the best practices in designing and developing simulation models in healthcare, either discrete event simulation (DES) or Agent-based Methods (ABM), is unfortunately scattered throughout the computing and operational research literature. Though there were early attempts to formalize the process by developing framework as introduced in [10][11].

The growing number and quality of software platforms for agent-based simulation ABS and DES is reflected in the variability of systems across applied domains. Disciplines that use ABS (e.g., biology, ecology, economics, political, science, sociology) have considered different tools such as Arena, Anylogic and MATLAB. The quality is difficult to determine as validity is scarcely reported[12] . Platforms in ABS and DES have ranged from being low-level, that mainly mean the simulation model was built from the scratch using general programming language, or high-level in which simulation specialized platform was used to build the model. A hybrid of the two approaches was also conducted in which the platform allow for the researcher to modify the logic behind the model by programming it. In this paper, we present a systematic literature review of simulation models in the context of healthcare to investigate the challenges and trends in this topic.

2. Simulation modelling in healthcare: a systematic literature review

Simulation modelling in the context of healthcare covers the scope of Healthcare management. Simulation types included discrete event simulation (DES) and agent based simulation (ABS) [13] . In this review of ABS and DES modelling systems, a trend of variability and scalability are evident. Table 1 lists recent ABS and DES systems, along with the platform used to develop the model, data sources used to build the simulation model.

Several digital libraries were included in the thorough search process that was conducted in this research, they are, ACM digital library, IEEE Explore, winter simulation and Journal of Simulation. Search terms used while exploring these digital libraries varied from being very broad such as " simulation" to being narrowed down to the specific field such as "simulation in healthcare'', logical operators were used to enhance the search such as " discrete event simulation + platform". The range of 2008-2015 publication year was considered. Inclusion criteria for publications that were considered relevant to this research were: the publication included a simulation model (either DES or ABM), the publication should mention the data source used to obtain required data and lastly the publication has to mention the simulation platform used to design the model. Papers were excluded for the following reasons: not specifying which simulation platform been used to build the model or not clearly stating the data source. The collection resulted in eighteen papers that fit the criteria is listed in Table1.

2.1. Chosen publications

The publications which specify the simulation type, simulation model, data source and simulation platform are listed in table 1.

Table 1. Simulation Systems in Healthcare.

Reference	Simulation type	Objective	Platform	Data source	Year
[14]	DES	Patient flow to clinks	AWESIM	Studies and statistics on the same problem	2008
[3]	ABM	Schedule ER dept. physicians	NetLogo	The system depends on dynamic data provided by the user prior to the simulation initiation	2008
[9]	ABM	Vaccine allocation	C++	Studies and statistics on the same problem	2009
[1]	DES	Modelling and analysis of the emergency	SIMUL8	Extracted from the Information System at the department	2010
[8]	ABM	Simulate population with a specific chronic disease	Anylogic	Studies and statistics on the same problem	2010
[15]	DES	maximize Thrombolysis for Stroke	SIMUL8	Random distribution numbers	2012
[16]	DES	model of sudden Cardiac death	MATLAB	Studies and statistics on the same problem	2013
[17]	ABM	Patient flow in ER	NetLogo	Extracted from the Information System at the department	2013
[18]	DES	Patient flow in ER	ARENA	Extracted from the Information System at the department	2011
[19]	DES	Patient flow in ER	ARENA	Extracted from the Information System at the department	2011
[20]	DES	Resource planning in the emergency departments	ARENA	Extracted from the Information System at the department	2015
[21]	DES	Performance of clinic operations	ARENA	Extracted from the Information System at the department , Studies and statistics on the same problem	2014
[22]	DES	Improve process of Cardiac Catheterization Lab	ARENA	Custom data collection	2011
[23]	DES	Improve performance of emergency medical service	ARENA	Extracted from the Information System at the department	2014
[24]	ABM	Improve performance of emergency department	Netlogo	Random distribution numbers	2011
[25]	ABM	Outpatient scheduling	ARENA	Extracted from the Information System at the department , Custom data collection	2014

3. Challenges and trends

3.1. Simulation platform

In healthcare, the systems that have been reported varied in using low-level simulation scripting languages such as C++ [9], or using intermediate-level simulation tools that incorporated low-level scripting with enhanced graphic interface such as MATLAB [16], or using high-level simulation frameworks with minimum needs of scripting such as Anylogic[8]. Results in table 1 shows shifting to high-level simulation tools rather than scripting languages. Figure 1 shows a trend of using ARENA in discrete event simulation was spotted. Netlogo was mostly the platform for Agent based simulation.

3.2. Engineering process

System engineering process was poorly reported in the founded literature apart from [26] which was published in a computing conference and described the iterative process of designing and modelling that was done. Interestingly , [17] have stated their iterative process to be as the called it ‘ cycles’.

The shortage in reporting might be due to the field of the publications was not relevant to software engineering. However, it was evident that the projects reported in the observed literature had followed a systematic process that started by identifying the objective of the simulation, obtain necessary data, build the conceptual model, develop that model and report results as reported in [1], [21], [27].

In agent based simulation framework was introduced in 2006 called The ODD Protocol [28], ODD stands for Overview, Design concepts and Detail, it consists in addition to the process above, the framework : documentation, calibration and scenario analysis as phases of any simulation project. Apart from [17]It was noted through the reviewing of the included publications that the ODD protocol doesn’t get addressed explicitly while reflecting on the simulation system.

3.3. Data collection

These simulation models are often based on data sources of historical data such as in [1], or real time data collected to serve the system [22], randomly generated data based on the fields’ probabilities [16].

In 2000 , the study in [29] have investigated the challenges being faced in simulation projects. They have emphasised on the unavailability of data in electronic format. Nowadays, with the growth in health information systems [30], half of the systems mentioned in Table 1 have used data extracted from Healthcare Information

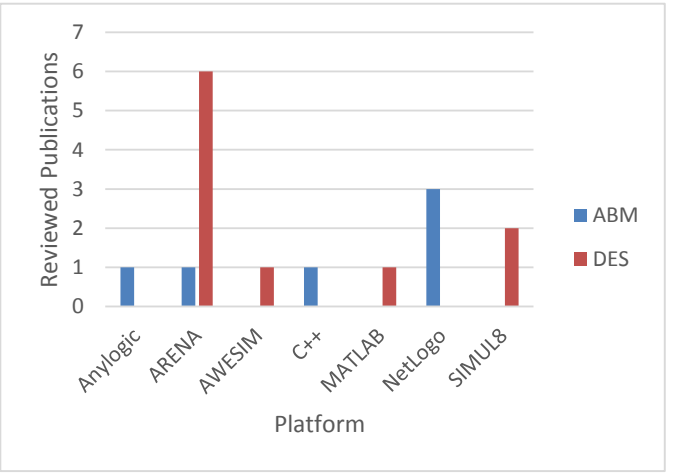

Fig. 1. Simulation platform per simulation type.

Systems. Though the problem may seems solved, however another challenge emerged as data stored in electronic records doesn't map directly to the simulation objective. An example of that was reported in [27], where researchers have extracted data from electronic records, and to be able to use it in their model they had to represent it as collective data.

3.4. GUIs and interaction modes

Similarly to software engineering process, graphic interfaces and interaction modes were overlooked while reporting about simulation systems. Apart from [1] [8] [21] and [27] in which it reported a graphic interface of the simulation model. For the sake of this investigation, we have also observed a random sample of healthcare

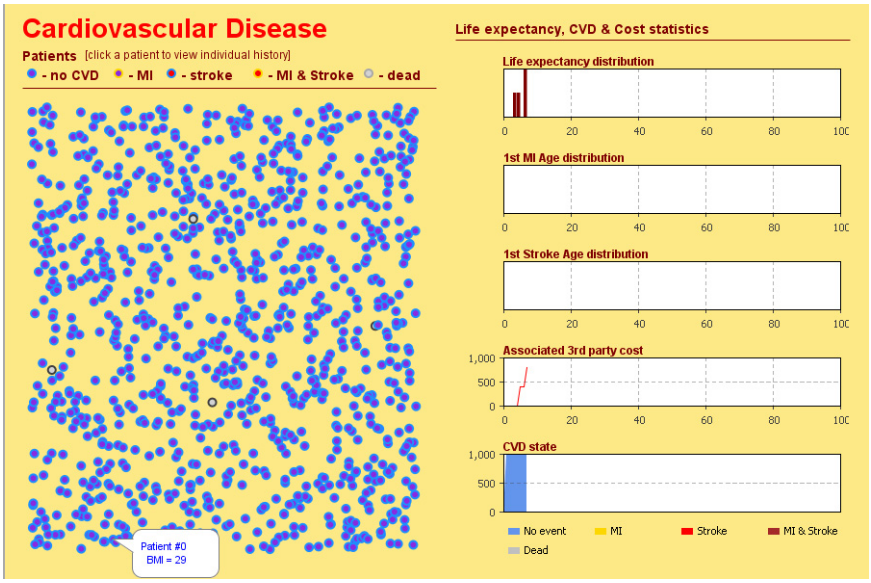

Fig. 2. A simulation tool developed in Anylogic.

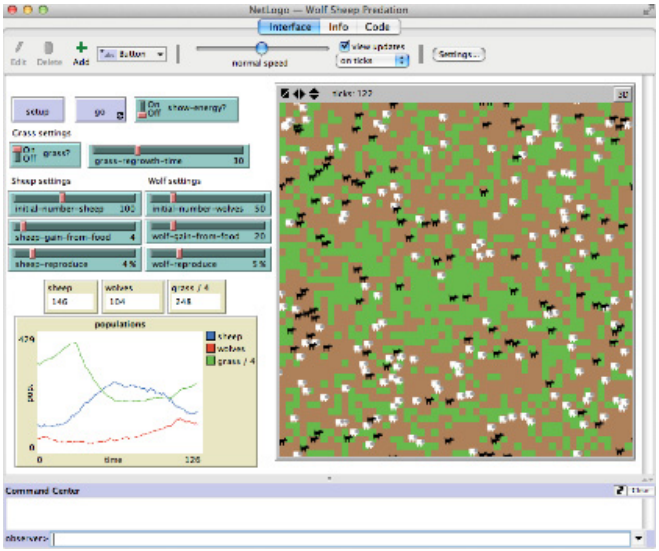

Fig. 3. A simulation tool developed in Netlogo.

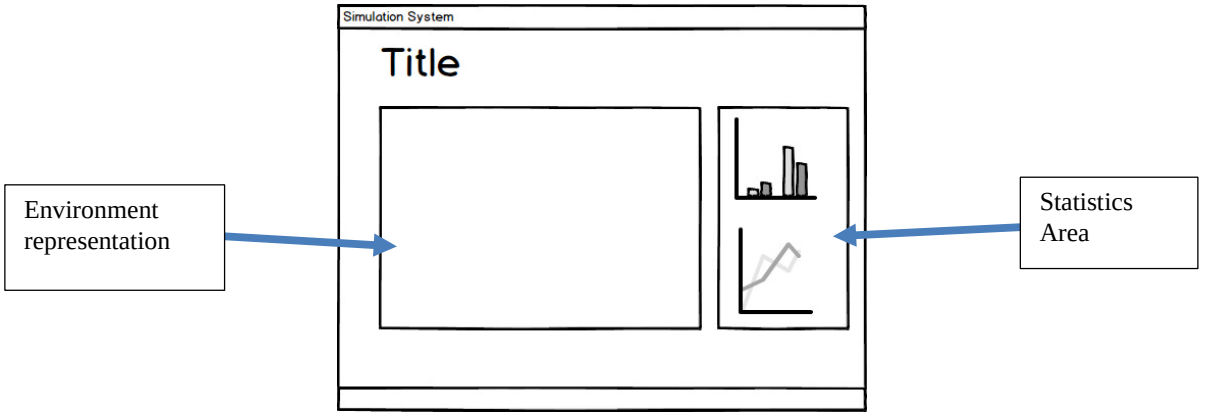

Fig. 4. Common layout of Simulation systems.

simulation systems available on online repositories such as (RunTheModel provided by Anylogic Co. and NetLogo Model Community). Figure 3 shows an anticipated of a common design framework for simulation tools.

Another trend observed through the reviewed publications in addition to the online models repositories, is how minimum manipulation these models offer, apart from model presented in [3] which allows the user to manipulate directly 18 variables. Visualization techniques in simulation models were similar across the reviewed publications, charts and graphs were used to represent the results of the simulations.

3.5. Agent characteristics

It was observed through the reviewed literature how agents were defined on different levels of details, some of researches defined agents with high level of abstraction [5][25] where other researches have designed detailed agents [8][31]. Agents in models concerned with scheduling [5][25] are often represented using high level attributes that are directly derived from the problem itself. Where publications of studying the spread of a certain disease [8][31] humanize agents by defining detailed socio-demographic attributes.

4. Conclusion

The evolution of simulation modelling in healthcare over the past two decades has been optimistic: more scientists and researchers are conducting exploratory research with advanced modelling as platforms evolve into more efficient contexts for implementation, while developers try to adapt ABM and DES platforms to the growing user communities in different disciplines.

The paper have explored the trends within the research community in simulation platforms used to designed these models, also a trend in data collection methodology was noted. A tendency towards a common graphic interfaces was also observed.

Agent characteristics in agent based models were examined in addition to the overall engineering process of discrete and agent based simulations.

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