

Modeling in Healthcare: Selection of Simulation Types

Mohd Kamal Mohd Nawawi^{1,2,*}, Jafri Zulkepli¹, Ruzelan Khalid^{1,2}, Norhaslinda Zainal Abidin^{1,2}

¹School of Quantitative Sciences, Universiti Utara Malaysia, 06010 UUM Sintok, Kedah, Malaysia

²Institute of Strategic Industrial Decision Modelling (ISIDM), Universiti Utara Malaysia, 06010 UUM Sintok, Kedah, Malaysia

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Abstract The nature of the healthcare system is crucial and requires health authorities worldwide to ensure every decision is made correctly and efficiently. Simulation modeling which is among the decision-making techniques, is generally used to represent the real systems of healthcare for the authorities to evaluate prior to any modification. A holistic understanding of the issues related to simulation types in healthcare is required. This paper reviews and summarizes publications related to various types of computer simulation tools in the healthcare domain, using the *Scopus* database. Based on healthcare applications and issues, this paper finalized five main types of simulations: 1) discrete-event simulation; 2) system dynamics; 3) agent-based modeling; 4) Monte Carlo simulation; and 5) hybrid systems. All of these types have continued to contribute to healthcare simulation modelling in recent years and more are expected in the future. In general, this review argues that future studies should focus on framework development that will support the selection of simulation types based on the problem.

Keywords Healthcare, Discrete-Event Simulation, System Dynamics, Agent-Based Modeling, Monte Carlo Simulation, Hybrid Systems

Modeling is one method for examining how real-world systems operate. It depicts and demonstrates how a specific system is interconnected with other systems in its environment. There are numerous modeling techniques for representing real-world systems. To model the integration of health and social care in healthcare systems, two types of modeling techniques have been widely used: simple modeling business process technique and simulation technique.

The simple modeling business process becomes a useful technique to picture the entire system of how it works, with the healthcare and social care model being no exception. Most simple business process models take a long time to develop before they reach a conclusion about whether or not to adapt the system. It necessitates a significant financial investment.

A simple business process model functions in the same way that a modeling does. It examines how the entire system operates and generates a framework or flow chart of the system. If the current systems are not performing well, the modeler will usually add some features or make improvements to the systems. After the setup or installation is complete, the experiment will begin. The experiment will take some time to complete. At the end of the experiment, the decision maker will have three options: continue with the current system, continue with the current system with some adjustments, or terminate the system entirely. Everything is dependent on the outcome of the experiment.

1. Introduction

Many researchers, including Sobolev [1], Walshe and Rundall [2], and Watt et al. [3], have stated that healthcare management should understand the impact or consequences of every decision they make before implementing it in the real world, because healthcare is a zero-tolerance sector for errors. As a result, the care sectors should seek or use tools that can provide a comprehensive view of any decision made by decision makers.

Given the limitations of simple business process modeling techniques, modelers are increasingly turning to simulation techniques. The main distinction between a simple business process model and a simulation is the process of experimentation until they reach a conclusion and make a decision on which initiative to implement. The model for a simple business process is implemented in the real world before experimentation, whereas the model for a simulation technique is built in a computer and the experimentation is done using computer simulation before implementation. The main advantage of the simulation technique is that it can mimic the dynamics of the real system [4].

1.1. Theoretical Background

As the premier international forum for disseminating recent advances in the field of system simulation, since 1967, Winter Simulation Conference (WSC) is one of the most prestigious simulation conferences [5]. However, the application of computer simulation in healthcare only started to be presented in WSC in the early 1990s. Among the earliest authors are Iskander and Carter [6] and Draeger [7] using discrete event simulation, Canner et al. [8] and Roberts [9] using Monte-Carlo simulation. Since then, more simulation applications and techniques have been discovered.

The simulation method consists of various techniques. These techniques have been used for a number of purposes in a variety of industries. Kuljis et al. [10] suggest how these techniques could be used in the healthcare sector. Table 1 shows how simulation techniques have been used in various industries for a variety of purposes, including how these techniques can be used in the healthcare industry.

Table 1. Simulation techniques applied in different industries and potential use in the healthcare sector (adapted from Kuljis et al. [10])

Sector/ industry	Purpose of application	Application to healthcare sector
Manufacturing	Enhancements to the manufacturing process, inventory management, and new product development	<ul style="list-style-type: none"> • Logistics services • Reengineering and management • Scheduling and queue management • Reduction of waiting times • Resource and asset allocation and management • Patient pathway design and management • Management of strategic and operational aspects • Change management • Management of demand and supply • Health economics • Analysis of risk • Management of risk • Decision making/support under conditions of uncertainty (e.g. in commissioning procurement, policy making, organizational change etc.)
Automobile	Improvements in the production process	
	New product development	
Construction	Logistics and operations, construction scheduling	
	Training, real-time planning, resource allocation	
	Incentives and disincentives-based contracting, construction scheduling, risk modeling	
	Supply chain simulation	
	Training, improving communication skills, and conveying concepts	
	Construction scheduling, risk modeling	
Energy	Management of assets	
	Power trading, market place simulation, competitive strategy, expansion planning	
	Emergency planning, energy pricing, power trading, market place simulation, competitive strategy	
	Expansion planning, market place simulation, power trading, financial analysis	
Pharmacology	Improvement in production process, new product development	
Process industry	Improvement in production process	
Biotechnology	Growth projections	

Some of the policy makers, or modelers or "ORticians" use the decision tools, especially the simulation types, based on their expertise, not on the problem at hand. Chahal [11] names this "fitting the nail into the hammer". Some of the tools that have been used are not suitable enough to capture certain variables or cater to the problems at hand. Barton et al. [12] have developed a framework of choosing the right simulation tools based on the problem at hand. The main approaches to modeling used in economic evaluations in health care are decision trees, Markov models and individual sampling models. These methods assume the independence of individuals within the model. Where interaction between individuals is important, other methods such as discrete-event simulation or system dynamics are preferable. However, the developed framework lacks some of the other types of simulation methods, such as hybrid simulation, agent-based modeling (ABM) simulation, and mathematical modeling. The framework is also too general and can be confusing for decision makers or modelers to find the right and suitable decision tool based on the problem at hand. As their framework is too general and can be confusing for those who are novices in the simulation area, especially in the healthcare area, it would be beneficial to develop a specific framework that can be used as guidance in selecting the best and most suitable simulation tools or types based on the problem at hand, in the healthcare area.

Pidd [13] argued that it should depend on the problems for the researcher to choose a good approach to model the systems. There are three questions that should be asked by researchers before choosing the best technique to model the system, which are: what should be simulated, why to simulate and how to simulate [14].

This study first embarked on capturing information about the healthcare systems and their problems, and then compiling information gathered from previously developed healthcare models. Then, the specific characteristics of the problems against their suitable

techniques based on the collection of gathered information are map. Simulation is an investigation technique in healthcare where the goals of a simulation vary in different projects: analysis of selected department load, policy making, building testbeds for the testing of various solutions, etc. [15].

Morecroft and Robinson [16] and Brailsford and Hilton [17] argue that studies about the difference between two dominant simulation techniques, system dynamics (SD) and discrete-event simulation (DES), are mostly biased as they are based on their personal opinions. There is no evidence collected from any empirical studies about the comparison between SD and DES [18].

1.2. Research Questions

The main question considered in this study is "What are the most widely used simulation types in healthcare?" This was further subdivided into three underlying research questions. Section 3 offers answers to all these questions.

RQ1: What are the approaches used in the existing literature on healthcare simulation modeling?

RQ2: What are the simulation types applied to healthcare systems published in impactful journal articles in recent years?

RQ3: Who are the main publication contributors in the area of healthcare simulation?

2. Methodology

This paper primarily employs the concept of systematic review [19] to identify real-world examples of how computer simulation techniques are used to solve problems in healthcare. The review process was conducted in August 2021. We used the Scopus database to search for related papers in healthcare and simulation techniques. The process began with a keyword search, as shown in Table 2.

Table 2. Search string used for the review process and number of records.

Keyword used	Number of records
TITLE-ABS-KEY (("simulation") AND ("healthcare"))	10370
TITLE-ABS-KEY (("simulation") AND ("healthcare") AND NOT ("system dynamics" OR "discrete event" OR "agent based" OR "monte carlo"))	8838
TITLE-ABS-KEY (("simulation") AND ("healthcare") AND ("system dynamics" OR "discrete event" OR "agent based" OR "monte carlo") OR "hybrid")	1765
TITLE-ABS-KEY (("simulation") AND ("healthcare") AND ("system dynamics" OR "discrete event" OR "agent based" OR "monte carlo"))	1532
TITLE-ABS-KEY (("simulation") AND ("healthcare") AND ("system dynamics" OR "discrete event" OR "agent based"))	1018
TITLE-ABS-KEY (("simulation") AND ("healthcare") AND ("system dynamics" OR "discrete event"))	792
TITLE-ABS-KEY (("simulation") AND ("healthcare") AND ("system dynamics"))	219
TITLE-ABS-KEY (("framework") AND ("simulation") AND ("healthcare") AND ("system dynamics" OR "discrete event" OR "agent based" OR "monte carlo") OR "hybrid")	221
TITLE-ABS-KEY (("framework") AND ("simulation") AND ("healthcare") AND ("system dynamics"))	39 22 (from 2015) 10 journal articles
TITLE-ABS-KEY (("framework") AND ("simulation") AND ("healthcare") AND ("discrete event"))	86 54 (from 2015) 26 journal articles
TITLE-ABS-KEY (("framework") AND ("simulation") AND ("healthcare") AND ("monte carlo"))	37 28 (from 2015) 26 journal articles
TITLE-ABS-KEY (("framework") AND ("simulation") AND ("healthcare") AND ("agent based"))	59 38 (from 2015) 14 journal articles
TITLE-ABS-KEY (("framework") AND ("simulation") AND ("healthcare") AND ("hybrid"))	53 43 (from 2015) 14 journal articles

Several words we used to search for articles that relate to simulation in healthcare, such as "healthcare", "discrete event simulation", "system dynamics", "agent based model", "simulation", "computer simulation" and so forth. Some of the words we combine together using the operator "and". More than 10,000 articles appear in the Scopus database. We then filtered the searching criteria to make it much smaller using the inclusion and exclusion criteria as shown in Table 3.

Table 3. The Inclusion and Exclusion Criteria

Criteria	Inclusion	Exclusion
Literature type	Journal (research articles)	Book series, chapter in books, conference proceedings
Publication timeline	2015-2021	2014 and before
Language	English	Non-English
Nature of the study	Computerized simulation	Role-play and in situ simulation

We select articles for specific years, i.e., 2015 to 2021, assuming that recent papers refer to previous papers. Therefore, the techniques to solve the same problem highlighted were using the same method or techniques. All theoretical papers or papers that do not have any

discussion of the results were excluded. The selected articles must be in the healthcare area only and apply any modeling and simulation techniques, either single or hybrid techniques, as long as they have used at least one simulation technique.

However, these articles were then filtered again, to select only articles that had discussion about their results. We excluded articles that do not have the final result as we need to see whether the simulation technique used is suitable or not for the particular problem. The discussion about the result(s) can be interpreted as successful or unsuccessful. If the results have some problems (unsuccessful), then we consider that the particular technique was not suitable to use, and vice versa. All selected articles were reviewed thoroughly and all important criteria will be extracted. Such criteria are specific types of problems that researchers intend to solve, the method used and the results discussed. Based on the criteria that we have setup, we managed to get 15 articles that suit our objectives for this research. Generally, the simulations involved in the research are system dynamics, discrete event simulation, Monte Carlo simulation, and agent-based simulation. Some of the research combined these techniques with other techniques in operational research such as optimization to optimize whether the

simulated results are fully optimized or not.

3. Results and Discussion

The analysis of the papers related to simulation types in healthcare can be categorized into five types. As depicted in Table 4, the types are DES, SD, ABM, Monte Carlo, and hybrid simulation.

3.1. Discrete-Event Simulation

Discrete event simulation (DES) is considered as the most widely used simulation type in healthcare. It provides a systematic approach to mimicking real systems at a micro level [20]. Even though DES is not a tool that will give the optimal solutions, "what if" scenarios could be analyzed in the model before modification or improvement is done to the real systems, especially in healthcare, which involves high risks or fatalities [20], [22]. Utilization of medical staff, including doctors and nurses, and waiting times and movements of patients are among the performance measures that are generally produced by DES [21]. DES usually comes together with queuing analysis since the performance measures of both techniques are similar [15], [23].

3.2. System Dynamics

System dynamics (SD), contradicts to DES is a highly

abstract method of modeling. It ignores the fine details of a system, such as the individual properties of people, products, or events, and produces a general representation of a complex system. These abstract simulation models may be used for long-term, strategic modeling and simulation. Comparison of two or more models' performance based on certain metrics such as average inventory levels, lead time, and unfilled orders could be done by SD [24]. It is a method for understanding the behavior of complex social and economic systems at the macro or strategic level [26], [34].

3.3. Agent-Based Modeling

Relatively new compared to DES and SD, ABM basically consists of a group of independent individuals (agents) that interact with each other. Generally, ABM complements the limitations of DES by incorporating human behavior simulation and people-environment interactions [29]. Garcia-Magarino et al. [27] proposed an ABM to simulate people's movements on a smart bed with load sensors to define sleeping posture recognition algorithms. Liu et al. [28] stated that the complexity of the different pathways patients may take and the inherent uncertainty and variability of healthcare processes warranted a study. Therefore, ABM provides a flexible platform for studying ED operations, as it predicts system-level behavior from individual-level interactions [28].

Table 4. The Finding – The Selected Articles

Authors	DES	SD	ABM	MC	Hybrid/ Applications
Al-Hawari et al. [20]	/				Multi-criteria decision making
Ordu et al. [21]	/	/	/		Forecasting and mathematical modeling hybrid with DES only
Gul et al. [22]	/				Artificial neural network
Kovalchuk et al. [15]	/				Queuing theory
Li et al. [23]	/				Pareto optimization, Queuing theory
Kochan et al. [24]		/			Supply chain management systems
Bolt et al. [25]	/	/			DES and SD
Kazemi et a. [26]		/			Bayesian belief network
Garcia-Magarino et al. [27]			/		Smart beds for data analytics
Liu et al. [28]			/		Emergency department
Yousefi et al. [29]			/		Emergency department
Alauddin et al. [30]				/	Risk analysis
Hassanhosseini et al. [31]				/	Performance of proposed algorithm
Lee et al. [32]				/	Statistical analysis, Markov chain
Parolini et al. [33]				/	Statistical analysis

3.4. Monte Carlo

A Monte Carlo simulation, quite different to the first three types of simulation, has been used in risk and statistical analysis [30], [31]. Lee et al. [32] built a Monte Carlo simulation study which shows that their proposed framework, in a range of data scenarios, performs better than their competitor analysis strategies. Normal Monte Carlo simulation normally involves data design and generation [33].

3.5. Hybrid

Each type of simulation has its own customized graphical approach, such as process flow for DES, causal loop diagrams for SD, and state diagrams for ABM [34]. Usually, hybridization of simulation types is used to combine both strategic and operational issues. Ordu et al. [21] combined DES with forecasting and optimization models, in a sequential flow. The outputs of forecasting were used as the inputs of the DES model, then the outputs from DES were used as inputs into the optimization model. Like DES, the performance of interest such as waiting times, length of stay, and duration of treatment was measured.

3.6. Comparison and Analysis

Additional analysis to longitudinally compare the simulation types was conducted in early November 2021. Extracted from the Scopus database, DES is the most published simulation type in healthcare modeling, with 646 publications. Figure 1 shows the frequency of all five simulation types since 1994. The second most is MC simulation, with 547 publications, followed by hybrid (331 publications), ABM (299 publications) and lastly, SD (222 publications).

We then filtered the data to see the most recent publications in the most impactful publications, which covers publications in journal articles for the period of 2015 to 2021 as shown in Figure 2. Surprisingly, MC was found to have the highest number of publications, with 273 articles, compared to DES, with 224 articles, as shown in Figure 2. Other types are hybrid (131 articles), ABM (97 articles), and SD (73 articles).

In terms of the most contributing authors in the field of healthcare simulation, the top five authors are Tillal Eldabi (29 publications), Navonil Mustafee (26 publications), Adam Cheng (23 publications), Debra Nestel (23 publications) and Bruce Lee (22 publications). SD and hybrid systems were found to be the most popular simulation types used by the first two authors. Among the authors' most frequently cited publications are [34]–[39], which are based on hybrid types.

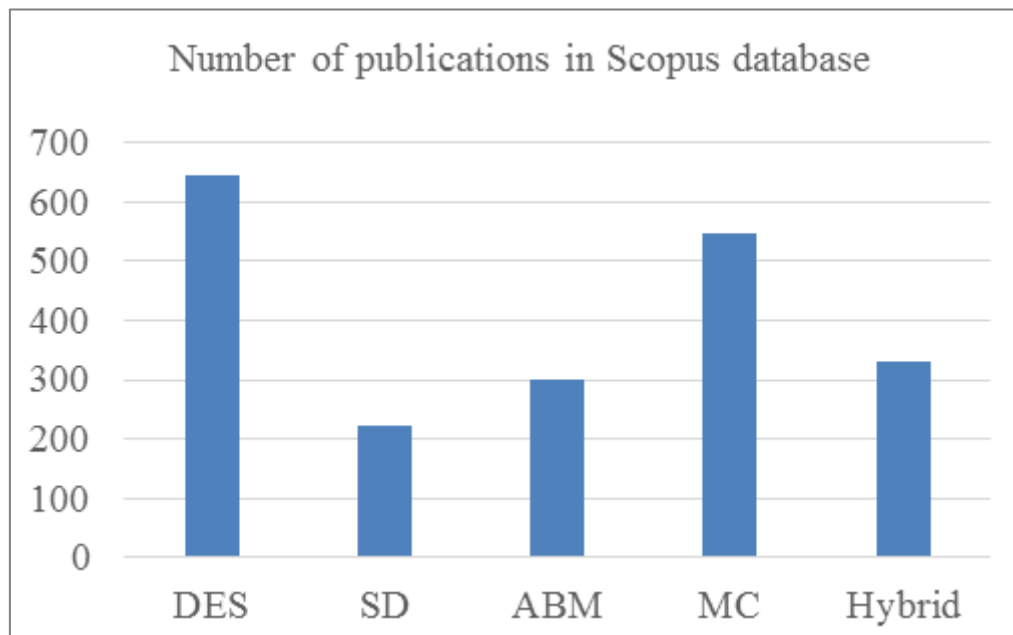


Figure 1. Frequency of the number of publications of five simulation types

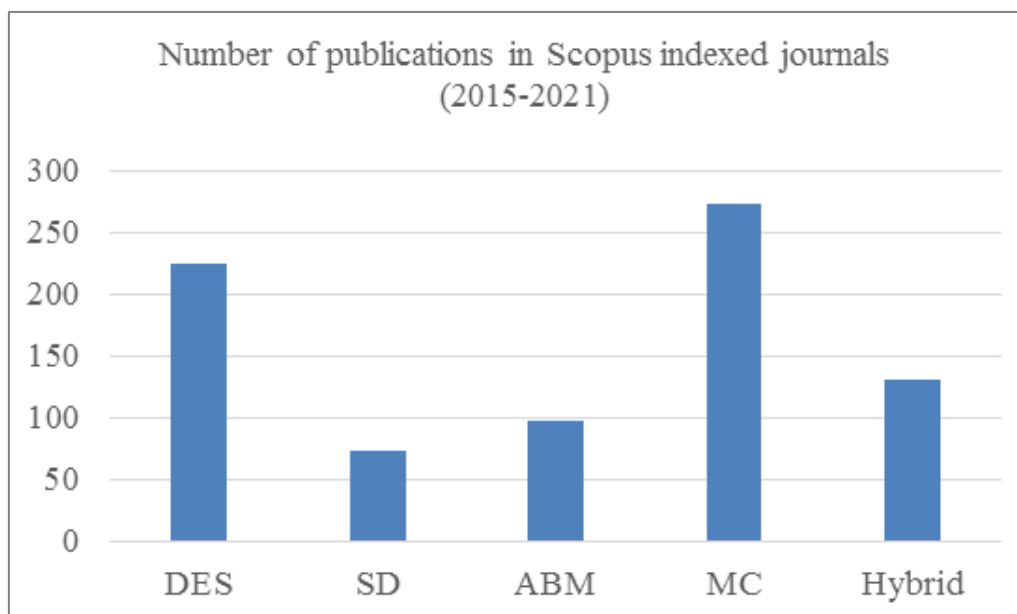


Figure 2. Frequency of the number of Scopus indexed journal publications of five simulation types for the period of 2015 to 2021.

4. Conclusions

In summary, DES focuses on the problems of queuing and processing, SD considers the world as a feedback system, ABM looks at an environment populated with autonomous beings, and Monte Carlo simulation is more about risk and statistical analysis. The combination or hybridization of any two or more types is needed when the problems could not be solved by any single model alone. In the future, we plan and hope to construct a decision support system that can be used in selecting simulation types for specific healthcare system problems.

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Conflict of Interest

The authors declare that they have no conflict of interests.

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