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Multi-Perspective Modeling of Healthcare Systems

Ignace Djitog, African University of Science and Technology, Abuja, Nigeria
Hamzat Olanrewaju Aliyu, Federal University of Technology Minna, Nigeria
Mamadou Kaba Traoré, Université Blaise Pascal, Clermont-Ferrand, France

ABSTRACT

This paper presents a multi-perspective approach to Modeling and Simulation (M&S) of Healthcare Systems (HS) such that different perspectives are defined and integrated together. The interactions between the isolated perspectives are done through dynamic update of models output-to-parameter integration during concurrent simulations. Most often, simulation-based studies of HS in the literature focus on specific problem like allocation of resources, disease propagation, and population dynamics that are studied with constant parameters from their respective experimental frames throughout the simulation. The proposed idea provides a closer representation of the real situation and helps to capture the interactions between seemingly independent concerns - and the effects of such interactions - in simulation results. The article provides a DEVS (Discrete Event System Specification)-based formalization of the loose integration of the different perspectives, an Object-Oriented framework for its realization and a case study as illustration and proof of concept.

KEYWORDS

Healthcare Systems, Multi-Perspective M&S, Output-To-Parameter Integration, Parameterized DEVS

INTRODUCTION

Being composed of concurrent, fragmented and diverse components interrelated with intricate processes, modeling the domain of healthcare will require the understanding of the behavior of the overall system (Barjis, 2011). Decision-making concerning questions related to the performance of HS - such as the extent to which the system achieves its mission - have no clear or simple answers while the need to produce more with less resource despite the scarcity is becoming a widely-acknowledged concern among policy-makers and healthcare managers worldwide. This is proven by a considerable volume of work published in recent years being dedicated to simulation-based study of HS. Frequently, modeling approaches used to investigate different aspects of HSs related to healthcare simulation include discrete event simulation, mixed method that combines simulation with optimization techniques, goal programming and discrete event simulation with data envelopment analysis (Weng et al., 2011). Arguably, unit specific studies of simulation modeling in healthcare that deals with specific problems have been predominant in the published research articles. Such unit specifics include A&E (Accident and Emergency Departments), inpatient facilities, and outpatient clinics (Choi et al., 2013). The common issues addressed in the literature include, but not limited to scheduling and patient flow, sizing and planning of beds, rooms, and staff.

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The main challenge in modeling a complex system such as HS is the large number of its components and their diversity. To the best of our knowledge there has not been a generic model of healthcare simulation that considers the different elements of HS and their interactions to describe a complete whole. This paper investigates HS through multi-perspective modeling and addresses the challenges that come with modeling such a complex system. Multi-perspective modeling allows constructing distinct and separate models from different aspects of HS for a better understanding of its complexity. Furthermore, an integrative approach based on live updates of output-to-parameters translation is developed to allow the simulation output of a model of a given perspective to update the simulation parameters of another perspective dynamically. Arguably, a closer representation of the real situations can be achieved if these parameters are systematically modified at runtime in such a way that the outputs of the simulation models corresponding to different perspectives provide live updates of their parameter(s) in concurrent simulations. Therefore, the formalization of the bases of the proposal is provided with a case study that presents the models of different perspectives in HS and shows how their integration is being achieved.

The rest of this paper is organized as follows: the next section presents the literature review followed by the multi-perspective modeling of HS. The DEVS-Based formalism for integrating HS perspectives is then presented with a case study to illustrate its application before concluding the paper with directions for future work.

LITERATURE REVIEW

Modern HSs have been explored with a variety of studies over many decades. Although not exhaustive, a number of examples of these studies include discrete event simulation, system dynamics, agent-based simulation, Monte Carlo simulation, hybrid simulation (combination of discrete-event and continuous) and simulation combined with optimization techniques. Roberts (2011) presented an extensive tutorial of such simulation modeling methods with a revision of taxonomy of the use of computer simulation in healthcare into two categories: Patient flow optimization and Analysis, and healthcare asset allocation. More specifically, Gunal and Pidd (2010) enlarged this taxonomy in a review of the literature for discrete event simulation for performance modelling in healthcare into scheduling and patient flow, sizing and planning of beds, rooms, and staff. Unit specific studies of simulation modeling in healthcare focusing on solving specific problems in individual HS units such as Outpatient clinics, A&E (Accident and Emergency Department),and Inpatient facilities are predominant in healthcare simulation literature.

Consequently, most of the published articles look into HSs with focus on a single perspective modelling. For example, patient pathway across different healthcare units has been regularly examined to identify critical activities and scarce resources representing process bottlenecks. Cote (1999) examined the daily arrivals and the throughput of patients to analyze the utilization and the allocation of examining rooms at a family practice clinic. Other than patient flow and resources utilisation perspectives, is the simulation modelling related to demand that includes epidemiology research and health policy-making. For example, an integrated agent-oriented modelling and simulation framework that considers both population and healthcare delivery network has been introduced by Charfeddine and Montreuil (2010). Okhmatovskaia et al. (2012) presented ontology for simulation modelling of population health (SimPHO) a formal, explicit machine-readable specification of a domain of knowledge integrating both aspects of taxonomy and vocabulary in a form of logical axioms. A perspective related to disease spread has also been considered by several models to predict its propagation in a pandemic and the effect of HSs intervention and is reported by the work of the authors Kasaie et al. (2013).

Similarly, simulation has been used as main tool for training medical students through studies such as serious games. Bruzzone et al. (2012) proposed an advanced serious game called MARIA (Model for Advanced and Realistic patient simulation driven by Intelligent Agents), that aims at