Healthcare Simulation and its Potential Areas and Future Trends

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ABSTRACT
With the projected growth in the aging population of the world, increasing waiting time for healthcare services, pressure for controlled costs, declining or vanishing subsidies and state funds, healthcare is undoubtedly an attractive domain for scientific exploration using simulation. In this article, we briefly discuss healthcare simulation, highlight some application areas, and identify the most relevant topics for future research. The research in this article follows the observation line and expert reflection backed by relevant literature. Although neither this is a roadmap nor a research agenda, effectively, this article sets a direction for a set of topics that can be a subject for independent research articles.

Keywords: healthcare modeling, healthcare simulation, healthcare modeling and simulation, healthcare process modeling, healthcare process simulation, healthcare simulation trend.

1 INTRODUCTION
Today’s global healthcare expenditure stepped into the over 5-trillion-dollar economic sector (WHO 2008) with most of the industrialized countries spending well over 10% of their GDP on healthcare (USA 16%), the issue of healthcare efficiency is becoming a buzzword in discussion with both healthcare managers and decision makers.

Healthcare delivery and services are undergoing dramatic changes due to the decreasing state supports, obligatory cost control, growing market competition, and transition to electronic health records (EHR). Changes are often met with resistance due to the risks and uncertainties that accompany them, which can be overcome if the impact of these changes are studied ahead, e.g., in a virtual environment such as a simulation setting. Simulation in healthcare allows replication of reality allowing exploration of possible changes, experiencing situations that otherwise will not be possible. This can be accomplished without heavy investment on the development of systems, training, or equipment purchase.

Furthermore, healthcare simulation can be extended beyond the traditional role of comparing scenarios or visualizing workflows. A simulation model can be incorporated as a component of ongoing efforts to monitor and improve performance and increase efficiency. In such a role, a simulation model is developed not only to conduct experiments, but anchored in the running information systems of the organization (Darema, 2004). This is done to study the behavior of a system in a longitudinal manner for advising adaptations and changes as the system operates and data are collected dynamically.

A true benefit of simulation can be harvested when the simulation models are fully integrated into the routine fabric of healthcare delivery, i.e., the existing information system applications which support the daily operation of the healthcare provider (Gaba, 2004). Essentially, the vision is not to treat simulation as a tool for conducting a one-time set of experiments when a major change is planned, but make the simulation models run in parallel to other applications as a routine part of the everyday work environment. With this approach, healthcare efficiency becomes an ongoing objective and the future may require even
tougher demands. Furthermore, with the rapidly changing variables of the healthcare system (technology, finance, policy, service demands, market, etc.), healthcare efficiency is becoming more of a moving target that needs to be periodically retargeted and re-addressed.

Emerging from past skeptics and resistance toward simulation, today healthcare is showing more maturity and the necessity for simulation to play a significant role in solving healthcare challenges. Moreover, the current economic situation, policy shift, and the environment in which healthcare is delivered are ripe for institutionalization of simulation as a standard tool supporting the steering, management, and control of healthcare delivery.

2 HEALTHCARE SIMULATION SCOPE

Simulation has a broad application potential in healthcare, which can be classified in a few major directions, formed around different disciplines or sub-disciplines. Each direction may have its own gradients or sub-directions as well. The following is a more general classification of healthcare simulation:

- **Clinical Simulation:** simulation is mainly used to study, analyse, and replicate the behavior of certain diseases including biological processes in human body.
- **Operational Simulation:** simulation is mainly used for capturing, analyzing, and studying healthcare operations, service delivery, scheduling, healthcare business processes, and patient flow.
- **Managerial Simulation:** simulation is mainly used as a tool for managerial purposes, decision making, policy implementation, and strategic planning.
- **Educational Simulation:** Simulation is used for training and educational purposes, where virtual environments and virtual and physical objects are extensively used to augment and enrich simulation experiment.

Managerial and operational directions of simulation are closely interrelated. These two together are the core components for healthcare process management. The clinical direction of simulation is also referred to as medical simulation.

The above classification is rather a departure point for a more pinpoint taxonomy of topics and only suggests the vast space of simulation applicability in relation to the healthcare domain. In each of the above directions, simulation can be used for analysis and design, learning and training, research and communication purposes.

An elaborated classification of healthcare simulation can be found in (Gaba, 2004), in which the author divides the healthcare simulation “application space” into 11 dimensions, each of which represents a different attribute of simulation.

In (Brailsford, 2007), the author classifies healthcare simulation models into three groups:

- Models of the human body, frequently called “disease models”, including biological processes in healthy individuals.
- Models for tactical purposes at the healthcare unit level (clinic, ward, department, hospital).
- Models for strategic purposes comprising system-wide models which often do not model individual patients at all.

All of these classifications demonstrate just how extensive the application space and potential of healthcare simulation are. However, the current research and practice of healthcare simulation are rather in the infancy phase compared to engineering fields. The full potential of healthcare simulation has yet to unfold, be explored and demonstrated.

3 HEALTHCARE SIMULATION POTENTIALS

Here we enumerate a few aspects for which healthcare simulation can be used as an effective tool, technique, or method. Improvement in any of the aspects, described below, will lead to the main goal -- healthcare efficiency.

3.1 IT Alignment

Development of national electronic health record (EHR) systems has created unprecedented opportunity for healthcare systems around the
world to transition to electronic health practice (eHealth) and to benefit economically from it. But the path for harvesting the benefits of eHealth lies through designing innovative healthcare processes and redesigning existing practices to cope with the changes resulting from the adoption of the new technology. The work by (Hillestad, 2005) estimates potential savings and costs of EHR in the US, which finds that effective implementation of HER (interoperable with other systems) could eventually save more than $81 billion annually. This saving is merely achieved by improving healthcare efficiency and safety. However, the author (Hillestad, 2005) recognizes that this is unlikely to be realized without related changes to the healthcare system. Thus, the simulation application in redesigning existing healthcare business processes and IT alignment is a critical scientific potential to explore.

3.2 Decision Support

Healthcare decision makers need reliable tools to support them in decision making for adapting policies to help cutting costs or reducing waiting time, and to provide visualization which allows them to rehearse innovative ideas before they are implemented. The tools should facilitate an evidence-based and informed decision making environment. Simulation models, especially with transparency into their structure and underlying variables, which can be easily understood and trusted by decision makers, are a helpful tool in decision support, communication and discussion of ideas and polices, and analysis of scenarios.

3.3 Training & Quality

Adequate training of clinicians has direct impact on the quality of service. It will reduce errors and promote the adoption of best practices. Training of healthcare staff (clinicians, administrators and managers) is costly, time consuming, and assumes commitments and dedication that are usually not embraced because of time constraints. Simulation can successfully enhance and improve clinicians’ expertise, accomplish acquaintance with new procedures and processes, and prevent errors that are caused by the lack of training and hands-on experience.

3.4 Complexity

The complexity of healthcare processes is growing exponentially, with various services like laboratories being outsourced, multiplication of specialties, and extreme mobility of patients resulting from competition in the free market. Modern hospitals are complex systems of distributed subsystems with intricate healthcare processes, human interactions, and inter-organizational workflows. For example, citizens easily can plan a different healthcare service based on less waiting time, prominent quality, or many other factors that lead them beyond their local, regional or even national borders. This makes healthcare processes more interconnected and more complex, and simulation can be a way of tackling such complexity. Thus, the complexity of healthcare systems makes simulation a potential tool for healthcare analysts (Lowery, 1996).

3.5 Process Improvement

In majority of healthcare simulation projects, where efficiency is the goal, the reduction of patient waiting time seems to be the main target. Both waiting for the service date and waiting while receiving service are important indicators of efficiency. Essentially, waiting time is the root cause of many problems healthcare is facing. Increased waiting time affects patients perception of the quality (Eilers, 2004), requires more space (waiting area), long waiting time for the service causes many no-shows and cancellation, and so on. If one was to conduct root-cause analysis of healthcare operational problems, patient waiting time would certainly appear in the root of many issues.

Apart from application potentials, healthcare simulation as a whole is facing a myriad of interesting scientific challenges, which open up a fascinating research domain for simulation researchers and practitioners.
4 HEALTHCARE SIMULATION CHALLENGES

4.1 Theoretical Challenges

4.1.1 Multi-Paradigm Approach
From what we discussed so far, it becomes evident that healthcare is a multi-disciplinary, complex field. As such, the main challenge of healthcare simulation is a theoretical breakthrough that should focus on: multi-methods (methods for formal and informal representation), multi-paradigms (discrete event simulation paradigm, continuous paradigm, agent-based paradigm), and multi-disciplines (organization, information, technology, policy, etc). Although diligent research has been conducted in relation to multiplicity of theories and paradigms, the current practice of simulation, in many aspects, is single-method, single-paradigm, and single-discipline minded.

The main objective and premise of multi-paradigm modeling and simulation is based on the idea of delivering a solution tool and theoretical framework allowing multi-level abstraction for the targeted domain and multi-perspective view of the domain problem (Atkinson & Kuhne, 2002; Mosterman & Vangheluwe, 2004) and providing for multi-disciplinary coverage.

4.1.2 User Acceptance
There is no doubt that the healthcare industry is now more prepared and ready to embrace simulation with all its capacity and potential. They are now fully aware of the values and the benefits simulation may yield to improve their operational and management processes. However, simulation is still a highly technical and sophisticated tool for common user comprehension, which triggers user resistance. User resistance is a major barrier to a successful simulation implementation in healthcare. This barrier exists in concert with the fact that simulation, especially detailed simulation, requires tremendous effort and time. These challenges require theoretical breakthrough. While expedition of simulation can be improved through innovative approaches such as development of different libraries, reuse of models, rich graphical interactive development environments, the reconciliation of users and the technicality of simulation models is still a least-studied research field.

4.2 Application Challenges

4.2.1 Data Collection
A simulation model can only be as good as the input data, yet the data collection is the main challenge in healthcare. In healthcare, often the simulation developers lack sufficient input data for their simulation models which then deliver rather approximate results. Data collection is a major challenge: historic data may not be available in a useful format; data collection should take place over a long span of time; talking to healthcare professionals for data collection and verification purpose is also a daunting task due to their busy schedules.

The input data need to be real and complete (not approximate), based on ongoing operation of the system (e.g., from information systems logs). As some hospitals may have more agile or dynamic staffing, one prominent role that a real time data-based simulation can play is prediction of nursing and staffing on daily basis, allocation of nurses between hospital and homecare operations, and many other suggestions which may arise from the benefits a simulation model delivers based on accurate and real data.

Ideal data collection may require, as we earlier discussed, integrating simulation models with the organization information systems (IS) which support the daily operation. As the other IS applications (e.g., appointment scheduling, operating room reservation, etc) create new data, these data are automatically fed into the simulation models. Anchoring simulation models into running IS applications will prevent many of the pitfalls that traditional simulation has (assumptions because of lack of data support or limited data range). This will allow the simulation model to be used for continuous improvement versus a one-time endeavor. For example, scheduling, which implies utilization of resources, alone will have a dramatic impact on the costs of operation and quality of delivered services, i.e., healthcare efficiency.

At present, since the input data are extensively simplified, the simulation outcomes are often used for a general forecasting and planning than
for daily decision making. A true need of healthcare systems to win the war of marginal profit is decision support data on a daily basis. This is where, in the pursuit of efficiency, simulation prevails over other analytical methods.

4.2.2 Healthcare Processes
Organizational and workflow complexity of the modern healthcare system is huge and extensive. Modern hospitals have a large number of interacting units consisting of specialized and acute units, third-party facilities, external labs, inter-hospital transfers. This complex collaboration and interaction contributes to a complex inter-organizational workflow and even a complex business model. The challenge of a simulation model is capturing this complexity of inter-organizational flow in a systematic and manageable manner. Models should adhere to certain qualities such as hierarchical representation, granularity, multiple views, etc. While rich in representation, at the same time, models should be still an easy means of communication and understanding among stakeholders, including those with no or moderate technical knowledge.

4.2.3 Verification and Validation
The real devil of simulation is in verification and validation, which is a subject of extensive research. Without profound verification and validation, it would be risky, if not disastrous, to make any decisions or forecasts based on the model outcomes. While the model-verification challenge can be relatively easy to overcome if using innovative modeling approaches, model validation, especially for complex models, is quite a challenge. One of the approaches to enhance model verification is an emerging approach of Collaborative, Participative, Interactive Modeling (Barjis, 2009), or CPI Modeling, in which models are designed collaboratively with participation of the users and business-process owners (Taylor, Robinson & Ladbrook, 2003; Weedman, 2008). Validation, however, is quite a different issue. Developing a valid simulation model, designing valid experiments based on the model, and carrying out a rigorous analysis of the experiments’ results pose a significant research challenge.

4.2.4 Conceptual Modeling
A simulation model is developed based on the understanding of a certain reality or controlled and confined universe. This reality is captured in conceptual models that serve as a blueprint for developing a simulation model and validating such a simulation model against its conceptual model. In the literature on healthcare simulation, one can see the discussion of problem domain and corresponding simulation model, tools, and software for simulation. However, the conceptual approach or model that lies between the problem domain and simulation model is largely overlooked. So far, research on healthcare conceptual model has been paid very little attention. Conceptual modeling, as a prerequisite of success in healthcare simulation, is a field of profound research. This research tackles both theoretical issues and application challenges that need to be addressed.

5 CONCLUSIONS
This article attempted to emphasize the potential of healthcare simulation both as a tool for intervention and a method for an in-depth study of clinical processes, healthcare delivery, patient flow, scheduling and forecasting of capacity, and strategic planning. In this article we summarized the major aspects of healthcare in which simulation yields benefits. Furthermore, we discussed key challenges that simulation specialists experience. We discussed data collection as one of top challenges as a simulation model based on limited input data lacks accuracy and delivers incorrect output. For conducting simulation across different dimensions (tactic and strategic), at least a cross paradigm approach is needed. We briefly discussed areas, where theoretical breakthrough and developments are needed to make simulation a holistic methodology for accurately and adequately conducting analysis and studying healthcare processes and dealing with their underlying complexity.

As healthcare simulation embarks on tackling major challenges, it might be worthwhile to adapt the experience of traditional fields. For
example, study of healthcare processes from the perspective or analogy of engineering processes, manufacturing processes, will benefit the future of healthcare simulation by bringing engineering knowledge into the field.

Another example of such a cross domain knowledge transfer is use of RFID for data collection in patient logistics.

Although this article had a limited scope, it is hoped that its discussion will serve as motivation for more in-depth research on specific topics, including those topics mentioned here.

REFERENCES

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