Dynamic Simulation Modeling to Evaluate Complex System Interventions for Health Care Delivery Research – What Methods for What Problems?

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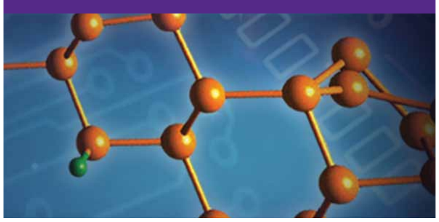
KEY POINTS . . .

A systems perspective using dynamic simulation modeling are useful to inform health care delivery planning and policy making.

Three dynamic simulation modeling methods could inform and broaden the science of health technology assessment (HTA): system dynamics, discrete event simulation and agent-based modeling.

The SIMULATE checklist can be used to assess if dynamic simulation modeling is appropriate to address the problem.



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A New ISPOR Task Force about Dynamic Simulation Modeling

In 2013, an ISPOR Task Force was established by the ISPOR Health Science Policy Council, to investigate new applications of simulation methods to evaluate the economic impact and outcomes of complex system interventions on health care delivery systems. This was due to the recent emergence of new types of health care delivery systems in the U.S., such as accountable care organizations (ACOs), and use of health technology assessment (HTA) throughout Europe and elsewhere which represent new levels of socio-behavioral interaction between different stakeholders in health care [1]. Given the complex, and often multi-faceted roles that providers, payers, patients, commercial industry, and government now compose in health care delivery systems, dynamic simulation modeling methods (DSMs) such as Agent-based Modeling (ABM), System Dynamics (SD) and Discrete Event Simulation (DES) may more efficiently portray many of the characteristics of these systems.

At the 17th Annual ISPOR European Congress, members of the ISPOR Simulation Modeling Emerging Good Practices Task Force presented a workshop to define the use of DSMs for simulating health care delivery systems in economic evaluation and health services and outcomes research. The workshop had three aims: 1) to describe when DSMs are appropriate to address a problem; 2) to describe and compare different DSMs for the design and evaluation of complex system interventions for health care delivery; and 3) to develop guidance on good practices for applying these DSMs. As a result of these aims, the task force developed a new checklist to guide modelers through the process of identifying whether DSMs are an appropriate application to a problem. Termed the "SIMULATE" checklist, this tool provides guidance on whether the use of DSMs are needed for the problem at hand [2].

What are System Interventions?

The health care delivery system represents a complex, multidimensional system of different stakeholders, technologies, and spatial diversity [3]. The complexities of these systems require significant overhaul in order to achieve improved quality, greater accessibility, and lower costs, as Berwick has prioritized for U.S. health care through the Triple Aim Framework [4]. Achieving this triple aim necessitates that stakeholders in health care develop creative system interventions to improve delivery efficiency. Like the systems themselves, these types of interventions can be complex and multidimensional in order to engage people, processes, and technology in systematic improvement.

Traditional outcomes research methods for which ISPOR has issued guidance documents in the past, such as decision trees and Markov models, take on a "causal perspective" and may not be able to completely portray the dynamics of complex

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system interventions. DSMs may be better suited to take a "systems perspective" since these methods capture relationally dependent events with unpredictable patient outcomes. In doing so, DSMs are able to examine scenarios considering reflexivity of both intended and unintended consequences of implementing complex system interventions in health care delivery systems [5]. DSMs also capture other complex elements of these interventions, including: feedback; nonlinear and spatial relationships; interactions between entities; and changes in agent behavior.

The SIMULATE Checklist to Help Guide Dynamic Simulation Modeling Methods

The SIMULATE checklist is a tool developed to evaluate whether the type of system being evaluated for an intervention is complex and possesses many of the characteristics that are uniquely captured in DSMs [2]. This tool is especially important since some issues can more easily be modeled using traditional modeling approaches (e.g. decisions trees and Markov models) rather than DSMs if the system being evaluated is less complicated, the data to populate such models are scarce, and computing power is restricted for some reason. However, if the former characteristics of a system prevail, then the SIMULATE checklist is a good tool to verify the use of DSMs, and offer guidance on whether ABM, SD or DES is most appropriate without discriminating against the use of a particular DSM.

Each item of the SIMULATE checklist possesses a specific definition to the classification of a complex health care delivery system for the use of DSMs. A definition of each component of SIMULATE is shown in Table 1 and described in the sections that follow:

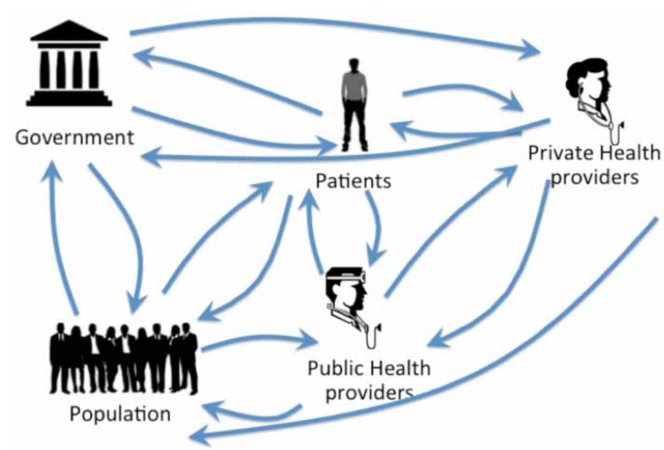
Table 1: The Outcomes Research Process.

SIMULATE	Does your problem require…
System	Modeling multiple events, relationships and stakeholders representing health care delivery processes?
Interactions	Including non-linear or spatial relationships between stakeholders that influence behaviors and make outcomes in the system difficult to anticipate?
Multilevel	Modeling a health care delivery problem from Strategic, Tactical or Operational perspectives?
Understanding	Modeling a complex problem to improve patient-centered care that cannot be solved analytically?
Loops	Modeling feedback loops that change the behavior of future interactions and the consequences for the delivery system?
Agents	Modeling multiple stakeholders with behavioral properties that interact and change the performance of the system?
Time	Time-dependent and dynamic transitions in a health care delivery system, either between or within health care system levels or in health status change?
Emergent	Considering the intended and unintended consequences of health system interventions to address policy resistance and achieve target outcomes?

First, system refers to the issue of whether a decision problem refers to the entire health care delivery system, or only a part of it. An entire system is being measured if different stakeholders interact, such as the contact between patients and providers, or patient-to-patient. In addition, many system levels are being monitored in the conduct of health care delivery, such as the transfer of patients between different hospital units (e.g. from the emergency department to critical care) or clinics (e.g. from hospital medicine to rehabilitative outpatient care).

Second, interactions refers to the nonlinear relationships that may exist between stakeholders during the delivery or utilization of health services (Fig. 1). Interactions are conditional characteristics of ABM, whereas entities in DES and SD generally do not exhibit interactions. Several examples, such as in the field of cardiology, can be used to highlight nonlinear relationships. For instance, patient behavior, such as medication adherence, diet and exercise may be nonlinearly associated with the risk of a cardiovascular event. Health care expenditures for cardiovascular patients are nonlinear and highly skewed. And geographic location may play an important role in how patients utilize inpatient, outpatient or emergency services for cardiovascular issues.

Figure 1. Stakeholders are organizations or groups of people whose interests are affected or whose decisions influence the health care delivery system. Many different stakeholders exist, and they are all interrelated in complex health systems.



Third, which the system being modeled is Multilevel, or in other words, that stakeholders are clustered into separate levels of health care delivery systems. In the simplest form, multilevel models take on the characteristics of panel data, where repeated measures (e.g. time-series) are clustered by entities such as patients or providers [6]. As data are aggregated for health care delivery systems, additional levels of clustering may begin to organize that can be incorporated into the model to affect how stakeholders interact.

Three system levels are defined as part of the SIMULATE checklist: a) operational level; b) tactical level; and c) strategic level. The operational level reflects logistical issues, where stakeholders such as patients interact locally within health care systems, and their behaviors impact utilization and the risk of disease progression. The tactical level reflects management issues, and references the accumulated experience of many stakeholders helping to inform decision rules that maximize the efficiency and effectiveness of care provided. Modeling at the tactical level still subject to operational-level characteristics including particular patient cases, especially outliers, or spatial proximity to different types of health care providers. Strategic level issues incorporate broad-sweeping interventions such as governmental policies. Strategic level modeling attempts to maximize cost-effective care based on >

population-wide decisions that can still affect individuals. Strategic level modeling is affected by population behavior, interactions, and nonlinear relationships more broadly, and data are typically aggregated from clusters of different operational- and tactical-level observations.

Fourth, understanding refers to a working knowledge of system complexity characterized by nonlinearities, interdependencies among system components, and behaviors of agents (e.g., patients and providers). These characteristics make it difficult to predict outcomes associated with particular changes to the system such as delivery of evidence-based practices to individuals with special needs that are not well known, thus a patient-centered approach.

Fifth, loops are common among complex systems, which integrate feed-forward or feedback adjustments. These loops imply that the system learns or adapts from previous experiences or from new policy interventions. For instance, physicians may change prescribing choices as new medications enter the market or new evidence about existing treatments become available.

Sixth, agents reflect whether stakeholders possess behavioral traits or not. Entities do not exhibit behavioral characteristics, whereas agents do. This item of the SIMULATE checklist does not rule out the need for using DSM, but may help differentiate modeler from applying ABM, or SD/DES depending on specific characteristics.

Seventh, time-dependent events can be well-measured in DSMs. These models can be used to calculate time-until or time-since an intervention has been implemented, then evaluate changes in outcomes throughout the system. Time also potentially reflects the first level of a multilevel model structure, whereby it is clustered by stakeholders.

Eighth, emergent behavior reflects the unintended consequences of system interventions that can be found through DSMs. This is because nonlinearities and interactions among agents over time and space add to system complexity, making simulation methods the appropriate choice for understanding changes in performance.

Three Different Types of Dynamic Simulation Modeling Methods

Agent-based Modeling (ABM). ABM is used to model dynamic, adaptive and autonomous systems and is well-suited for public health planning. This approach has several core elements that stand it apart from other DSMs. The primary trait of ABM is that it models agents of behavior, which are active, individual objects that make decisions, have preferences, and specific characteristics and attributes (e.g. patients, doctors, or managers). The environment of ABM is also worth noting, since it promotes interactions between agents and with the system itself, such as throughout different organizational levels, geographical areas, or local hospital wards.

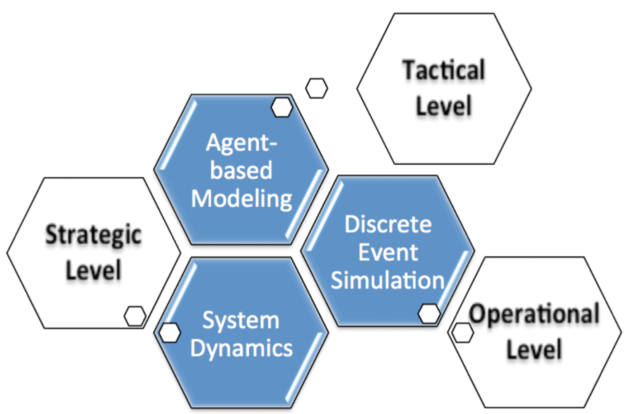
ABM has multiple core assumptions, such as the fact that agents are a heterogeneous mix of individuals with differentiated goals, beliefs and choices. Agents make decisions, adapt and learn from their interactions with other agents and the environment. ABM also is governed by the fact that it models its environment with the capacity for change and adaptation. As the environment changes, so do the behaviors and interactions between agents.

System Dynamics (SD). SD modeling is used for representing structure of complex systems and understanding the behavior of system entities aggregated over time. The behavioral characteristics of the system are actually due to its structure rather than external factors. The structure of the system can include nonlinear feedback loops as well as changes to accumulations (i.e. stocks) and rates (i.e. flows). From these structural elements of systems, SD modeling can be used to study patterns, trends and population health means.

Discrete Event Simulation (DES). DES is used to characterize and analyze queuing processes and networks of queues where there is emphasis on the use of resources. The events that DES models are important and specific moments in a health care system's lifetime, such as a surgery that changes the trajectory of a patient's outcome or utility. Queues, as defined in DES, are waiting lines that patients often encounter when seeking out health services with limited availability or high-demand. Outcome measures of DES are typically measured in the form of mean values and their distributions.

DES models entities rather than agents, which are stakeholders that do not exhibit true behavior or interactions between each other. Entities flow through processes and have work done on them, such as medical procedures. DES assumes that the primary way that entities and resources interact is through queues, resource availability and system constraints. Resources are objects that are used by entities in the workflow processes, such as health services.

Figure 2. Matching dynamic simulation modeling methods (DSMs) with categories of health care system-level evaluations.



Discussion

Three types of DSMs – agent-based modeling, discrete event simulation, and system dynamics – offer efficient ways of modeling complex system interventions in health care delivery systems (Fig. 3). These modeling approaches possess powerful, and potentially more accurate modeling of people utilizing health services. More traditional methods of modeling health care delivery systems, such as decisions trees and Markov models, have been criticized for over-generalizing what-if scenarios that patients can encounter as services are utilized. DSMs are methods that factor in unintended consequences resulting from human behavior, person-to-person interactions, and feedback on multiple system levels to more realistically depict health care delivery systems that span diverse populations.

The ISPOR Simulation Modeling Emerging Good Practices Task Force offers some guidance about the use of different types of DSMs depending on the cases being modeled [7]. For instance, SD modeling works well at the strategic level in order to inform health systems about the effects of large-scale interventions such as changes in health policy. DES performs well at the tactical and operational level to study person- or cohort-specific interventions. ABM has been shown to span all three system levels as defined in this report according to its application in different cases. Nonetheless, the three types of DSMs explored by the task force have significant overlap in their use, and depend on the types of data being modeled.

The data used to model these DSMs are an important consideration as the field of outcomes research moves forward with the application of these methods. The field of health services research is at an inflection point in its history as large datasets become available which contain numbers of observations and parameters not previously encountered. These data potentially hold information that can be interpreted as elements of behavior, interactions, feedback, etc. These data also are being abstracted from systems such as electronic health records with the ability to be formed as panels with multiple levels of clustering, thereby improving the power of DSMs. Depending on the structure of the data and the type of DSM software being used, multiple different DSM approaches could be developed from a single case of interest.

Ultimately, researchers with access to large datasets can begin to use DSMs in order to not only describe, but also predict the economic factors of health care delivery systems with the implementation of complex system interventions. Economic modelers who are interested in applying DSMs to specific questions that incorporate elements of health care delivery systems described in this report are recommended to refer to the SIMULATE checklist good practices which appeared in the January/February and March/April 2015 issues of *Value in Health* [2,7].

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Additional information:

To view Dr. Padula's presentation, please visit the Released Presentations page for the 19th Annual International Meeting at: http://www.ispor.org/Event/ReleasedPresentations/2014Amsterdam. You may also access the Simulation Modeling Emerging Good Practices Task Force Reports at: http://www.ispor.org/simulation-modeling-apps-hc-delivery.asp.

For additional insight, refer to Simulation Modeling Emerging Good Practices Task Force Chair Deborah Marshall's Q & A session with *Value & Outcomes Spotlight* Editor-in-Chief, David Thompson on page 43.

You may also access the Simulation Modeling Emerging Good Practices Task Force Reports at: http://www.ispor.org/simulation-modeling-apps-hc-delivery.asp.