SIMULATION MODELING
APPLICATIONS IN
HEALTH CARE DELIVERY
RESEARCH

Presented by: Deborah Marshall, Maarten IJzerman, William
Crown on behalf of the ISPOR SIMSYS Task Force

June 2, 2014

EMERGING GOOD PRACTICES
TASK FORCE

Overview of SIMSYS Task
Force

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Calgary, Calgary, Alberta, Canada
Objective

To develop guidance for outcomes researchers and decision makers on simulation modeling methods that can be applied in research on health care delivery system interventions.

The task force will:

1) Describe and compare applications of various simulation modeling approaches for the design and evaluation of complex system interventions for health care delivery; and.

2) Develop guidance on good practices for applying these simulation modeling methods in this context.

Rationale

Emerging Area in Health - The feasibility and relevance of simulation modeling methods to inform health system planning and decision making to improve system efficiency have been demonstrated, but current lack of guidance about selection and application of appropriate methods for research in health care delivery interventions. [Brailsford, 2009]

Relevance of the Science - Operational Research Society recently launched Health Systems, promoting the idea that all aspects of health and healthcare delivery can be viewed from a ‘systems perspective’.

Policy Context - Triple Aim framework as foundation for Accountable Care Organizations of the Affordable Care Act with a systems-based approach to improving health care (experience of care, health of populations and reducing per capital costs of care). [Berwick, 2002 and 2008]

ISPOR Task Force can add value for members by providing a primer to lay the basic foundation for applying these methods in health care delivery systems research.
An overview and examples of three advanced methods suitable for simulating interaction between health care delivery and system interventions:
- agent-based modeling (ABM)
- discrete event simulation (DES), and
- system dynamics (SD) modeling.

The report will:
- help researchers and decision makers to identify which simulation modeling methods work best given health care delivery intervention characteristics.
- identify key steps for good practices in simulation modeling of system interventions in health care delivery systems.

“Complexity is generally used to characterize something with many parts where those parts interact with each other in multiple ways.”

- Wikipedia
Complexity is a property of a system not an intervention.

A complex system is one that:

- Involves relationally dependent events with unpredictable outcomes. [Zimmerman, 2001; Glouberman, 2002]

- Is adaptive to changes in its local environment, is composed of other complex systems (for example, the human body), and behaves in a non-linear fashion (change in outcome is not proportional to change in input). [Shiell, 2008]

- Complex health care systems include primary care, hospitals, and chronic care.
Health Care Delivery System Interventions

- Health care delivery system interventions are complex, multidimensional interventions, including:
  - people,
  - processes, and
  - technology.

- Tasks that are relationally dependent events with unpredictable outcomes. They can be evaluated using various simulation modeling techniques to examine scenarios considering intended and unintended consequences of an intervention.
**Task Force Members (1)**

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- **William Crown, PhD**, Chief Scientific Officer, Optum Labs, President ISPOR, Boston, MA, USA
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Why Simulation Modeling is Relevant for Healthcare

Maarten J. IJzerman, PhD, Professor of Clinical Epidemiology & Health Technology Assessment (HTA); Head, Department of Health Technology & Services Research, University of Twente, Enschede, The Netherlands
Many health care and health system interventions are complex and require sophisticated analytics to support decision makers.

Health economic modeling as used in HTA is useful insofar the decision maker can trade costs per QALY on a societal level in a static and isolated cohort.

Yet, such models make major assumptions in regard to:
- Dynamics of healthcare delivery interventions
- Uptake of new or alternative health policies
- Availability of resources and resource constraints
- Planning of new facilities

They can estimate the consequences of healthcare delivery.

They allow the incorporation of behavioral aspects.

They are much more flexible to consider consequences of co-morbidities and frequent healthcare use.

They can consider the spatial consequences of a healthcare delivery intervention.

They can be used to evaluate and optimize a healthcare intervention given constrained resources.
**Simulation modeling approach**

“Undertaking a review of modeling and simulation in health care is without doubt a Herculean task”

Brailsford *et al*, J. Simulation, 2009

Hercules was the greatest of the Greek heroes, a paragon of masculinity, the ancestor of royal clans who claimed to be Heracleidae and a champion of the Olympian order against chthonic monsters.

Extraordinary strength, courage, ingenuity, and sexual prowess with both males and females were among his characteristic attributes.

**Dynamic Simulation modeling**

- Modeling “dynamic” rather than “statistical” interactions
  - i.e. definition of a system state and its evolution over time
  - States may include health status, risk behavior or cumulative costs and QALYs

- Simulation modeling vs. Markov models
  - Non-linear, i.e. assume dynamic interactions where Markov models consider isolated cohorts
  - Allow modeling of behavior, where individual behavior may deviate from the population
  - Markov models can be solved a priori due known statistical interactions, yet simulation models requires they be executed over time
Simulation Modeling Methods

- Task force identified three simulation modeling methods on which to focus:
  - Systems dynamics modeling
  - Discrete-event simulation
  - Agent-based modeling

System dynamics

- A simulation modelling methodology used for defining, understanding and discussing complex problems within complex systems at the population level.
- Developed in the 1950s by Jay Forrester at the Massachusetts Institute of Technology (MIT).
- SD can be used for policy analysis and design for problems in complex social, managerial, economic and ecological systems.

A Novel System Dynamics Model of Female Obesity and Fertility

Nasim S. Sabourouchi, PhD, Peter S. Holmmand, PhD, MSW, Nathaniel O. Oyagud, PhD, Roland F. Dyck, MD, and Emily S. Junghelm, MD, MSCI

More than half of women of reproductive age in the United States are overweight or obese. This situation raises a number of health concerns, but most pronounced for many of these young women is the fact that obesity is related to subfertility, often as a result of anovulation associated with polycystic ovary syndrome (PCOS). Also of concern, obesity is associated with serious obstetrical risks, including pre-eclampsia, gestational diabetes, and stillbirth. Perhaps most concerning for society is that maternal obesity increases the offspring’s risk for future obesity as well as obesity-related conditions such as diabetes.

Because of the known risks associated with maternal obesity, clinicians often encourage obese women with subfertility to lose weight before they initiate fertility treatment. However, deferring fertility treatment involving weight loss can be prohibitive for some women. Therefore, our objective was to create a system dynamics model specific to weight gain and obesity in women of reproductive age that could inform future health policies and have the potential for use in preconception interventions targeting obese women.

METHODS
The system dynamics model was developed using Vensim (Ventana Systems, Inc.) and simulated using the built-in solver. The data points used in the model were derived from various sources, including published studies and national databases. The model was validated using data from a large cohort of women of reproductive age who had undergone fertility treatment. The results from the model were compared with observed outcomes in the cohort, and the model was adjusted as necessary to improve its accuracy.

RESULTS
The model demonstrated that obesity and weight gain in women of reproductive age affect fertility outcomes in various ways. Specifically, obesity and weight gain are associated with reduced likelihood of conception, increased risk of miscarriage, and decreased live birth rate. The model also showed that weight loss interventions can improve fertility outcomes, but the timing and duration of weight loss interventions are critical factors.

CONCLUSIONS
Our model highlights the importance of understanding the impact of obesity on fertility outcomes. The model can be used to inform the development of interventions that target weight loss and improve fertility outcomes in women of reproductive age. Further research is needed to validate the model’s predictions and to determine the most effective strategies for weight loss in this population.

Figure 1: Causal map outlining basic elements that may affect projected changes in body weight over time among obese women of reproductive age.

Note: The causal map demonstrates the complex interactions between sociological and physiological factors contributing to obesity and suggests an intervention strategy for weight loss. reviewer suggestions are shown in the highlighted links and variables.

This latter point is particularly important given the current limitation of obesity treatment options.
Discrete-event simulation

- A simulation method used to characterize and analyse specific processes and use of resources originally in business and industrial settings.
- DES first emerged in the late 1950s and was developed by KD Tocher when working at the Operational Research group at United Steel Companies in the UK.
- Most problems are those regarding resource utilization and queues i.e. wait times. In addition, DES can be useful to also analyse effects on health related outcomes.

Discrete event: example

Using simulation to determine the need for ICU beds for surgery patients

Philip Marc Troy, PhD, and Lawrence Rosenberg, MD, PhD, Montreal, Quebec, Canada

Background. As the need for surgical ICU beds at the hospital increases, the mismatch between demand and supply for those beds has led to the need to understand the drivers of ICU performance.

Method. A Monte Carlo simulation study of ICU performance was performed using a discrete event model that captured the events, timing, and logic of ICU patient arrivals and bed stays.

Results. The study found that functional ICU capacity, i.e., the number of occupied ICU beds at which operative procedures were canceled if they were known to require an ICU stay, was the main determinant of the wait, the number performed, and the number of cancellations of operative procedures known to require an ICU stay. The study also found that actual and functional ICU capacity jointly explained ICU utilization and the mean number of patients that should have been in the ICU that were parked elsewhere.

Conclusion. The study demonstrated the necessity of considering actual and functional ICU capacity when analyzing surgical ICU bed requirements, and suggested the need for additional research on synchronizing demand with supply. The study also reinforced the authors’ sense that simulation facilitates the evaluation of trade-offs between surgical management alternatives proposed by experts and the identification of unexpected drawbacks or opportunities of those proposals. (Surgery 2009;146:608-20.)

From The Sir Mortimer B. Davis Jewish General Hospital, Montreal, Quebec, Canada
As described by Gunal (2012), ABS is a simulation method for modelling dynamic, adaptive, and behavioral systems.

In 1971, Thomas Schelling used ABMS to propose a theory to explain the persistence of racial segregation even though the legal and cultural environment was one of growing tolerance.

ABMS been applied to market forecast, human migration and movement patterns based on behavior. The widest use in population health has been to model large-scale anthropogenic or natural disasters, such as infectious disease outbreak.

Diffusion of innovations in social interaction systems.
An agent-based model for the introduction of new drugs in markets

Julio Pombo-Romero · Luis M. Varela · Carlos J. Rico

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Abstract The existence of imitative behavior among consumers is a well-known phenomenon in the field of Economics. This behavior is especially common in markets determined by a high degree of innovation, asymmetric information and/or price-inelastic demand, features that exist in the pharmaceutical market. This paper presents evidence of the existence of imitative behavior among primary care physicians in Galicia (Spain) when choosing a higher degree of coordination over the average is particularly influential. The evidence presented, together with the proposed model, might be useful for the design of optimal strategies for the introduction of new drugs, as well as for planning policies to manage pharmaceutical expenditure.

Keywords Technological diffusion · Small world networks · Ising model · Complex economy ·

Fig. 2 The introduction of a new drug for hypercholesterolemia (ceftimoxib) shows a network structure of non-local level. The existence of exogenous effects from social interaction among prescribers facilitated the rapid dissemination of the technology.

April 2004 · June 2004 · July 2004

November 2004 · February 2005 · April 2005
### Selecting Simulation Modeling Methods for Different Problems

<table>
<thead>
<tr>
<th>System Level</th>
<th>Types of Problems</th>
<th>Examples of Simulation Modeling Method</th>
<th>Intervention Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strategic level</td>
<td>Policy</td>
<td>SD/ABM</td>
<td>Regional or national policy regarding payment system for doctors – Fee for service vs. salary; Implementation of a centralized intake system at a regional level for referral to a specialist.</td>
</tr>
<tr>
<td>Tactical level</td>
<td>Management</td>
<td>ABM/DES</td>
<td>Wait time management at a specific location or a specific service e.g. Emergency Room; MRI</td>
</tr>
<tr>
<td>Operational level</td>
<td>Logistics</td>
<td>ABM/DES</td>
<td>Inventory policy at Children’s Hospital for oxygen tanks</td>
</tr>
</tbody>
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Why the Need for Good Practices? (1)

- Translation of evidence into policy and clinical care through implementation in the healthcare system are core issues around the world.
- The hierarchical relationship between health system, providers and patients demand a level of complexity that can be captured using simulation modeling.

Why the Need for Good Practices? (2)

- Lack of clear and accessible guidance for using simulation modeling methods to evaluate interventions in healthcare delivery systems.
- Traditional health technology assessment and modeling methods often of limited usefulness when applied to health systems.
- Developing good practice guidelines will advance the application of simulation modeling methods in health.
Criteria for selecting simulation modeling method
  - Purpose of the model: What is the model for?
  - Object of study: What is the problem?
- Model design and assumptions
- Documentation: pre, during, post
- Model building strategies
- Data Requirements
- Model validation
- Analysis of outputs
- Reporting

Our draft task force report will be ready for review in mid-July.

Dynamic Simulation Modeling Applications in Health Care Delivery Research

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OR

- Email Elizabeth Molsen (emolsen@ispor.org)