

## WORKSHOP

# DYNAMIC SIMULATION MODELING TO EVALUATE COMPLEX SYSTEM INTERVENTIONS FOR HEALTH CARE DELIVERY RESEARCH – WHAT METHODS FOR WHAT PROBLEMS?

Presented by: William Crown, Deborah Marshall,  
Maarten IJzerman, William Padula  
on behalf of the ISPOR Simulation Modeling Applications in  
Health Care Delivery Research Task Force



## **EMERGING GOOD PRACTICES TASK FORCE**

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## *Outline*

- 1) Overview of how a systems perspective and simulation modeling are useful to inform health care delivery planning and policy making
- 2) Description of the SIMULATE Checklist to determine if simulation modeling is appropriate to address the problem
- 3) Overview of 3 simulation modelling methods: System Dynamics, Discrete Event Simulation and Agent Based Modeling and illustrative example
- 4) Interactive exercise using the SIMULATE Checklist

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## Overview of Simulation Modeling for Health Services Delivery

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Chief Scientific Officer  
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## 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 when simulation modeling is appropriate to address the problem
- 2) describe and compare applications of various simulation modeling approaches for the design and evaluation of complex system interventions for health care delivery; and
- 3) 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'.



## Rationale

- ⊙ **Policy Context** - Triple Aim framework as foundation for Accountable Care Organizations in the U.S. 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.



## Content of Report

- ⊙ An overview and examples of 3 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.



## 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)

- ⊙ **Chair: Deborah Marshall, PhD**, Canada Research Chair, Health Services & Systems Research; Associate Professor, Department Community Health Sciences, University of Calgary, Calgary, Alberta, Canada
- ⊙ **William Crown, PhD**, Chief Scientific Officer, Optum Labs, Boston, MA, USA
- ⊙ **Mitchell Higashi, PhD**, Chief Economist, GE Healthcare, Barrington IL, USA
- ⊙ **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



## Task Force Members (2)

- ⊙ **Lina Burgos Liz, MPH, MSc Ind Eng**, System Dynamics Team, Universidad de los Andes, Bogotá, Colombia
- ⊙ **Nathaniel Osgood, BS, MS, PhD**, Associate Professor, University of Saskatchewan, Department of Computer Science, Associate Faculty, Department of Community, Health & Epidemiology and Bioengineering Division, Saskatoon, Saskatchewan, CA
- ⊙ **Kalyan Pasupathy, PhD** Co-Scientific Director, Healthcare Systems Engineering, Center for the Science of Health Care Delivery, Mayo Clinic, Rochester, MN, USA

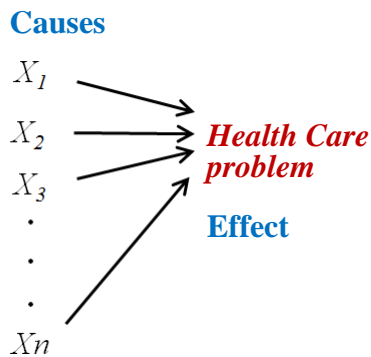


## Task Force Members (3)

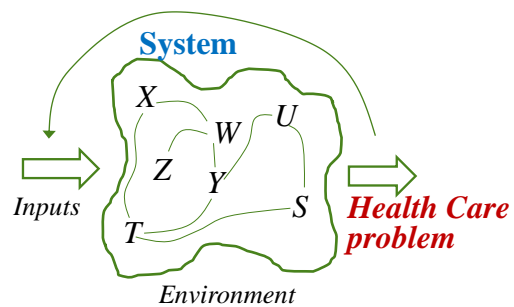
- ⊙ **William V. Padula, PhD, MS**, Postdoctoral Fellow, Section of Hospital Medicine, University of Chicago, Chicago, IL, USA
- ⊙ **Peter Wong, PhD, MS, MBA, RPh**, Vice President and Chief Performance Improvement Officer, Illinois Divisions and HSHS Medical Group, Hospital Sisters Health System (HSHS), Belleville, IL. USA



### Causal Perspective



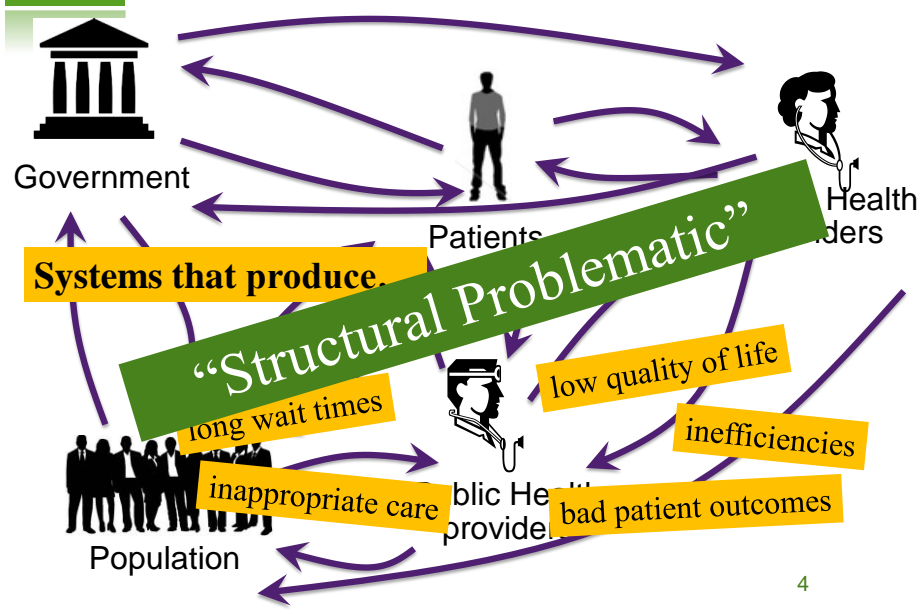
### Systems Perspective



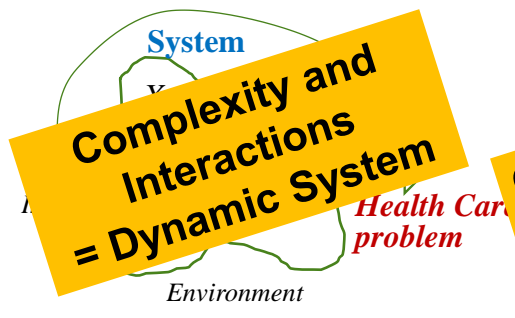
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### HealthCare System Stakeholders



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**Complexity and Interactions = Dynamic System**

Healthcare delivery processes...

Include for...

**Quality & Healthcare Improvement through System re-design**

behaviors and make outcomes difficult to anticipate

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## Why a Systems Perspective and Simulation Modelling for Planning Health Care Delivery?

- Health Care is a **Complex System**: multiple stakeholders and interactions, non-linearities, uncertainty, etc.
- Simulation models support the design and re-design of systems by enabling a better understanding of the complexity and behaviour of the system that is modelled. This translates into quality and healthcare improvement.
- Models are means to synthesize data when direct experimentation is not possible or feasible.
- Mechanism to logically and systematically examine a policy problem.
- Evaluate intended and unintended consequences of an intervention using alternative “what if...?” scenarios BEFORE implementing.
- Identify need for additional data – what are the gaps?

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## What is simulation modeling used for?

**What is simulation modeling used for?**  
*Health Care Delivery Research in Complex Systems*

- Model building process and simulation are learning processes themselves
- Identify critical functional and relational aspects in complex systems.
- Understanding system behavior as a

**What do we build simulation models for?**  
**Formalizing models and testing them via simulation can produce relevant changes to how we understand the system and how to intervene in it to generate the changes we want**

if...?” scenarios

- Tool for designers (e.g. policy design, system design and re-design) that is more prescriptive in nature by informing decision making.

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## SIMULATE Checklist

**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



## *Why we need a checklist*

- ⊙ There are multiple reasons why simulation modeling adds to the skillset of the decision modeler.
- ⊙ Although some good reasons for applying simulation modeling exist, other approaches may also be applied to similar problems.
- ⊙ The SIMULATE checklist has the objective to guide analysts to arrive at the decision to use simulation modeling approaches, but not dictate such decisions.
- ⊙ The more boxes that are checked, the more likely simulation modeling is to apply.
- ⊙ The SIMULATE checklist does not (yet) discriminate between the different simulation modeling approaches (ABM, DES and SD).

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# Checklist - SIMULATE

| SIMULATE              | Does your problem require:  |
|-----------------------|---|
| <b>S</b> ystem        | Modeling multiple events, relationships and stakeholders representing healthcare delivery processes?  |
| <b>I</b> nteractions  | Including non-linear or spatial relationships between stakeholders that influence behaviors and make outcomes in the system difficult to anticipate?  |
| <b>M</b> ultilevel    | Modeling a healthcare delivery problem from Strategic, Tactical or Operational perspectives?  |
| <b>U</b> nderstanding | Modeling a complex problem to improve patient-centered care that cannot be solved analytically?   |
| <b>L</b> oops         | Modeling feedback loops that change the behavior of future interactions and the consequences for the delivery system?                                 |
| <b>A</b> gents        | Modeling multiple stakeholders with behavioral properties that interact and change the performance of the system?                                     |
| <b>T</b> ime          | Time-dependent and dynamic transitions in a healthcare delivery system, either between or within healthcare system levels or in health status change? |
| <b>E</b> mergent      | Considering the intended and unintended consequences of health system interventions to address policy resistance and achieve target outcomes?         |

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**S**ystem Modeling multiple events, relationships and stakeholders representing healthcare delivery processes?

- Decision Problems comprise the entire healthcare delivery system.
  - Entities that interact
  - Patients who navigate the system
- Example:

Cardiovascular patients may transition from outpatient settings to the hospital when they have an acute myocardial infarction (AMI), subsequently be discharged to rehabilitation therapy, and then finally return to the outpatient setting once more.

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## Interactions Including non-linear or spatial relationships between stakeholders that influence behaviors and make outcomes in the system difficult to anticipate?

- Patient behaviors, such as medication adherence, diet and exercise may have a non-linear relationship with their risk of cardiac events.
- Health care expenditures for cardiovascular patients are nonlinear and highly skewed.
- Aggregate implications of patient health behaviors for the healthcare system are extremely difficult to predict.
- Patient geographic location may have strong influences on their pathway of care and the choices for treatments.

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## Multilevel Modeling a healthcare delivery problem from Strategic, Tactical or Operational perspectives?

- The treatment of cardiovascular disease is important at several levels of the health care system.
  - **Operational level:** Patient behaviors have a strong impact on their risk of events, as does their interaction with the health care system itself (their doctor, local emergency room, hospital, etc.).
  - **Tactical level:** Accumulating the experience of many patients can help to inform the development of decision rules to maximize the efficiency and effectiveness of care provided subject to the characteristics of a particular patient's case, spatial proximity to different types of health care providers, etc.

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## Multilevel Modeling a healthcare delivery problem from Strategic, Tactical or Operational perspectives?

- **Strategic level:** Attempts to maximize the cost-effectiveness of cardiovascular care must account for patient behaviors, nonlinearity of healthcare expenditures, and interactions with health care providers.

Data must be accumulated over the entire cardiovascular patient population served by the healthcare system to evaluate policies that will lead to the most cost-effective care.

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## Understanding Modeling a complex problem to improve patient-centered care that cannot be solved analytically?

The complexity of systems characterized by nonlinearities, interdependencies among system components, behaviors of agents (e.g., patients and doctors) makes it very difficult to predict outcomes associated with particular changes to the system such as treatment protocols for a patient arriving in the emergency room with an AMI.

Traditional modeling approaches such as Markov models, decision trees, and multivariate methods can be helpful in understanding pieces of a system but are not generally adequate to understand outcomes at a system level.

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## Loops

**Modeling feedback loops that change the behavior of future interactions and the consequences for the delivery system?**

Systems of cardiovascular care have integrated loops that may feed forward or feed backward. For instance, the a surviving patient who has experienced an AMI can learn to modify their medication adherence, exercise and diet behaviors. This, in turn, affects their subsequent risk of a future event and associated health care utilization such as re-hospitalizations.

The system may also integrate feedback loops, which actually implies 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 arise.

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## Agents

**Modeling multiple stakeholders with behavioral properties that interact and change the performance of the system?**

- Patients, doctors, and informal care providers are all examples of agents that interact with one another and other components of the health care system.
- Patient behavior at any time  $t$  is influenced by the consequences of their experiences in previous periods, their expectations for the future, their interactions with different health providers.
- The treatment choices of physicians are influenced by the outcomes of their previous patients, availability of alternative treatment options, emergence of evidence in the literature, and many other factors.
- Each of these behavioral responses is, in itself, very complex but their interaction makes it virtually impossible to predict outcomes without the use of simulation methods.

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## **Time** Time-dependent and dynamic transitions in a healthcare delivery system, either between or within healthcare system levels or in health status change?

- Time is an inherent component of any health care system.
  - One cardiovascular patient might spend 50+ years putting on weight and failing to take their statin and blood pressure medicine before ending up in the hospital with an AMI.
  - Their hospital stay might last 15 days before they are sent to the rehabilitation center for another week.
  - Finally, they return home, modify their diet and medication behaviors and live for another 40 years.
  - Another patient with a similar profile, might return home but develop depression and continue their poor health behaviors—eventually developing congestive heart failure and dying 5 years later.
- MI



## **Emergent** Considering the intended and unintended consequences of health system interventions to address policy resistance and achieve target outcomes?

- Nonlinearities and interactions among agents over time and space can lead to such complexity that it is only possible to understand the performance of the system through simulation.
  - Emergent behaviours can range from valuable innovations to unfortunate events.
  - Policy resistance is related to emergence. Due to the complexity of the system, a particular policy intervention may fail because policy makers do not fully understand its mechanisms and can't anticipate certain consequences or effects that may emerge.
  - The introduction of electronic medical records (EMRs) might be expected to improve the information available to physicians when making treatment decisions. However, physicians may resist using EMRs because they feel that it interrupts their interaction with the patient during the care process.
- MI



# Simulation Methods and Example

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Canada Research Chair, Health Services & Systems  
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## Examples of Problems Addressed with Simulation Modelling

| System Level      | Type of Problem | Problem Example  |
|-------------------|-----------------|--|
| Strategic level   | Policy          | Informing health policy regarding implementation of centralized intake for referral to appropriate provider for assessment and specialist consultation for patients with musculoskeletal pain.   |
| Tactical level    | Management      | Wait time management for referral for a specific service e.g., consultation with orthopaedic surgeon or rheumatologist   |
| Operational level | Logistics       | Scheduling surgical dates for joint replacement in the operating room<br>Evaluating the change in hospital services due to a delay of total joint replacement in cases of severe osteoarthritis. |

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## System Dynamics

- Used for representing structure of complex systems and understanding their behaviour over time in the aggregate
- Core assumptions:
  - Behaviour of the system is due to its structure and not external factors
  - Structure: feedback loop structure (processes) and structure of accumulations and rates.
- Core elements:  
Stocks: accumulations  
Flows: rates  
Feedback processes (nonlinearity)
- Outputs
  - Patterns and trends and mean values

DM



## Discrete Event Simulation

- ⊙ Used to characterize and analyze queuing processes and networks of queues where there is an emphasis on use of resources
- ⊙ Core assumption: the primary way that entities and resources interact is through queues, resource availability, constraints.
- ⊙ Core elements:
  - ⊙ Entities: objects that flow through the processes and have work done on them e.g. patients
  - ⊙ Resources: objects that are used in the workflow to process entities e.g. health care services
  - ⊙ Events: important and specific moments in the system's lifetime e.g. surgery
  - ⊙ Queues: waiting lines
- Outputs
  - Mean values and distributions

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## Agent Based Modelling

- Used to model dynamic, adaptive and autonomous systems and is well suited to public health planning
- Core elements:
  - Agents: active individual objects that make decisions, have preferences, and specific characteristics and attributes. e.g. patients, doctors, managers
  - Environment: system where the agents interact with each other and with the system. e.g. organization, geographical area, hospital ward
- Core assumptions:
  - Agents are heterogeneous and have goals, beliefs and choice; they make decisions, adapt and learn from the interactions with other agents and the environment.
  - Environment has the capability of changing and adapting.

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## Simulation Model Example

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## What is the problem with OA care?

- ⊙ Osteoarthritis (OA)
- ⊙ Population with OA
- ⊙ In

**How can health policy makers and service planners consider multiple factors to make decisions regarding health service delivery and planning for OA care?**

... human and  
variability of patient subpopulations e.g.  
comorbidities

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## OA Simulation Model – System Dynamics

To create a decision-support tool for strategic service planning of care for hip & knee osteoarthritis patients

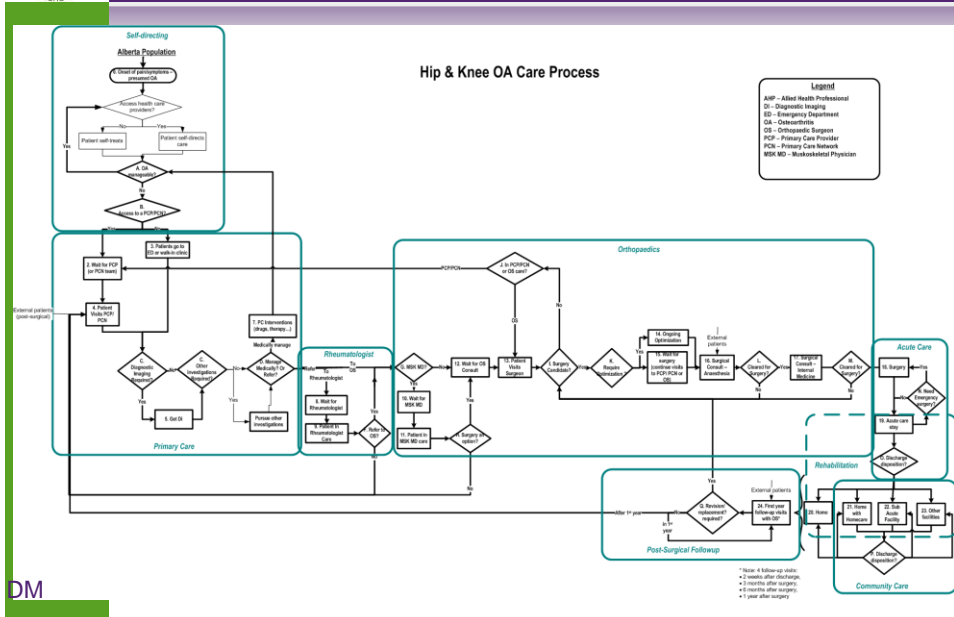
- Tool to enable policy makers, service planners and administrators, and clinicians to evaluate care quality and system performance
- Balancing the tradeoffs between accessibility, effectiveness and efficiency across the continuum of care from OA onset, through medical and surgical management
- Inform choices about health system interventions considering intended and unintended consequences

**Goal: Sustainable plan for OA care**

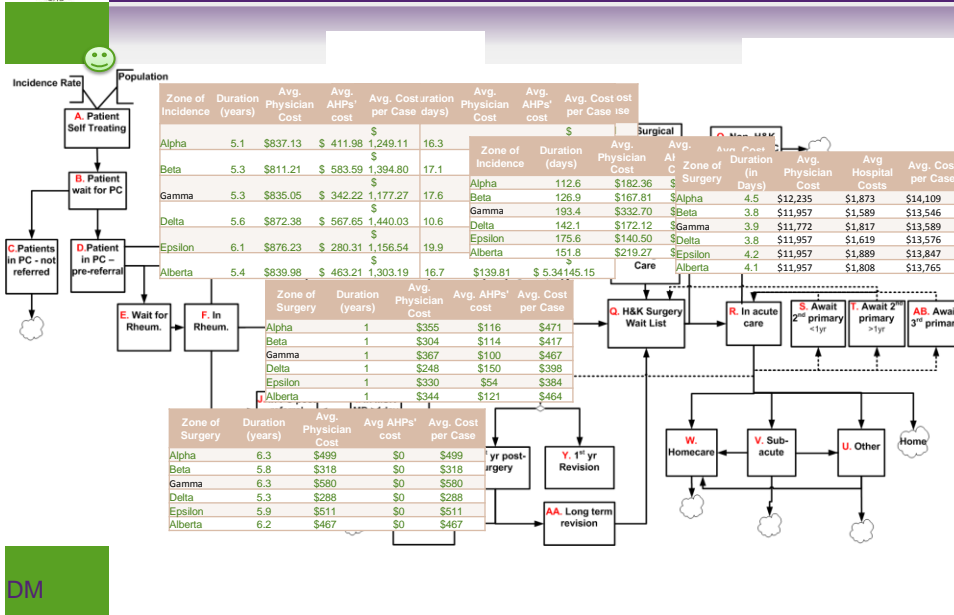
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# OA Care Process Pathway



# Sample Patient Pathway From Primary Care to Orthopedic Surgeon





## Example 'What if' Scenario With SD Model

### As an Example...

#### ⊙ Implementing a 14 week surgical wait time scenario

How many joint arthroplasties are required to meet the surgery wait time target of 14 weeks now and in the future, considering the dynamics of OA in the population over time?

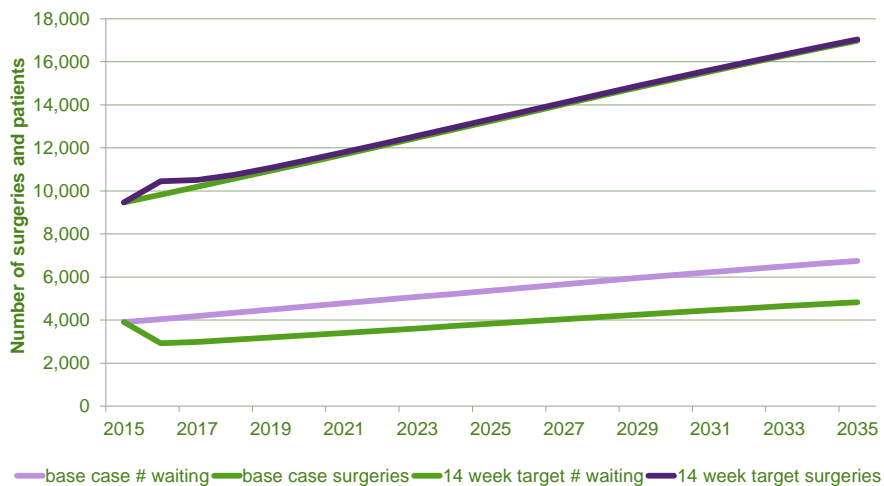
What are the associated changes in demand for health care services?

What are the associated changes in cost for health care services?

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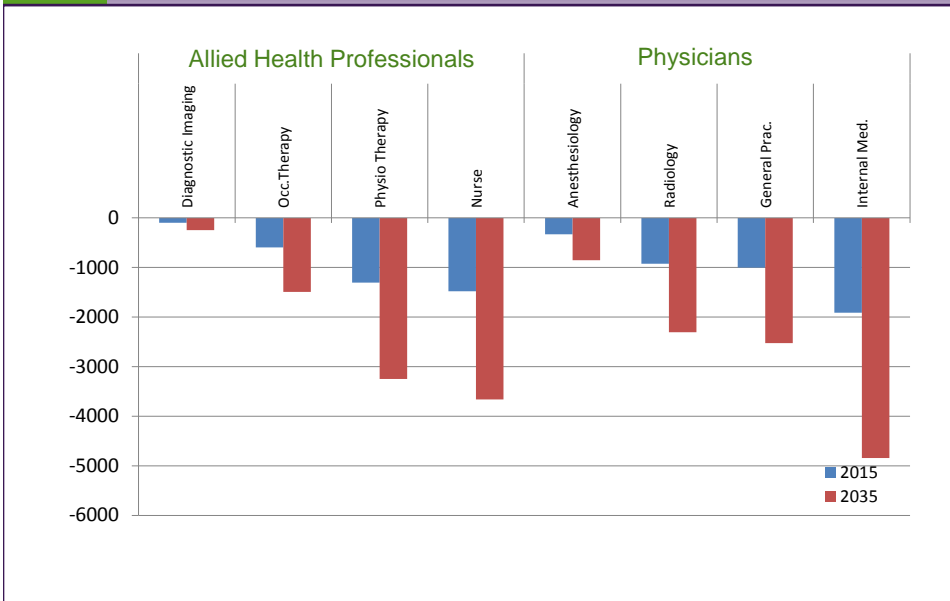
## Long Term Surgery Rates are Similar to Rates Without the 14 Week Target



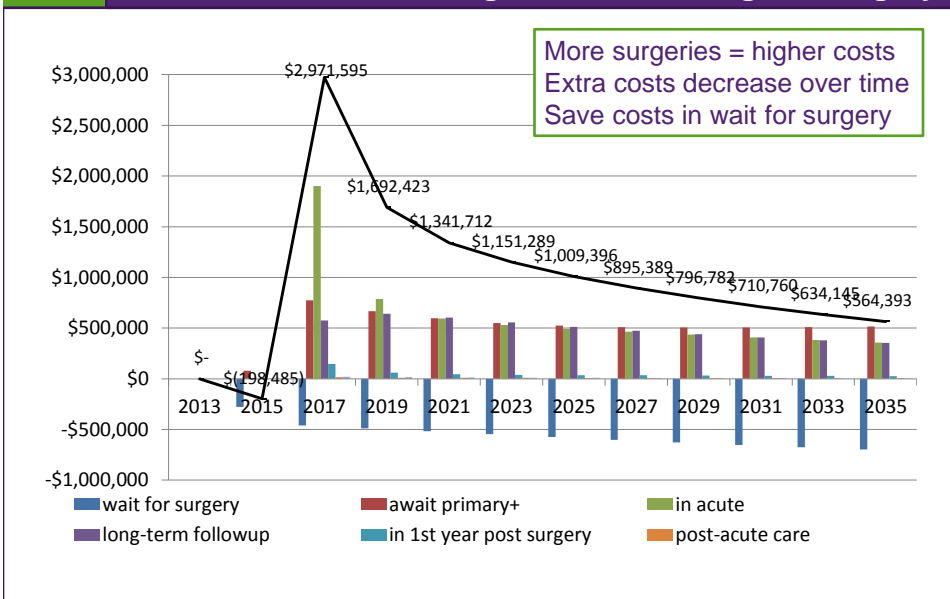
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## Changes in Health Care Use Due to Shortened Wait Time



## Costs of Performing Additional Surgeries to Maintain Target are Offset by Savings Achieved Through Lower Health Care Use Among Patients Waiting for Surgery





## *Interactive Use of SIMULATE Checklist*

**William V. Padula, PhD, MS,**

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Medicine, University of Chicago

Chicago, IL, USA



## *The Rules of Interaction*

- ⦿ We will show you several case analyses at multiple levels.
- ⦿ For each case we will walk you through the SIMULATE checklist.
- ⦿ Please vote on choice method for simulation model.



## Case 1: A strategic-level problem

- ⊙ Build new Emergency Department (ED)?
  - ⊙ The flow of patients through the hospital limits ED capacity
  - ⊙ Hospital-patient flow is limited by flow to ICU, as well as general medicine and surgery
  - ⊙ An additional ED on-site or at adjacent facilities would increase patient capacity
- ⊙ Other Factors to consider
  - ⊙ Patients who undergo surgery have prolonged ICU stays
  - ⊙ As ICU length of stay increases, hospital flow from ED decreases
  - ⊙ Highly comorbid populations contribute to greater ICU stays



## Case 1: A strategic-level problem

- ⊙ Downstream Consequences
  - ⊙ Hospitals with slow throughput have reduced profitability relative to fixed, capitated payments.
  - ⊙ Bed capacity should be a balance between ED admissions and inpatient follow-up for comorbid conditions.
  - ⊙ The rate of surgical procedures could be limited by bed capacity afterwards.



## Case 1: A strategic-level problem

- ⊙ System: Health care processes in place?
- ⊙ Interactions: Are there spatial relationships between providers and taking care of patients?
- ⊙ Multilevel: A strategic-level problem, but are other levels involved?
- ⊙ Understanding: Are patient centered-care issues at play here?
- ⊙ Loops: Feedback or feed forward occurring?
- ⊙ Agents: Is human behavior a factor here?
- ⊙ Time: does time play a role?
- ⊙ Emergent: Are there unintended consequences?

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## Case 2: A Tactical-level problem

- ⊙ Long wait times in the Emergency Department (ED)
  - ⊙ Patients who seek care at a proximal ED can have abnormally long wait times
  - ⊙ Wait times are longest in the early-evenings most weeknights, and worst on Friday and Saturday nights
  - ⊙ Wait times are lowest in early-mornings
- ⊙ Other Factors to consider
  - ⊙ Wait times are dependent on downstream factors such as empty beds in the hospital
  - ⊙ The hospital lacks a residency program in emergency medicine
  - ⊙ Recent employee unionization led to shorter hours for full-time providers (nurses and physicians)
  - ⊙ The hospital can hire “moonlighter” physicians to raise hours at an increased hourly rate



## Case 2: A Tactical-level problem

- ⊙ Considerations
  - ⊙ Hospital wants to optimize ED wait time by improving provider capacity at most economical balance of full- and part-time providers
  - ⊙ Wait times varying by time and day
  - ⊙ EDs are in close competition with each other, so consistently high wait times can affect future patient arrivals
  - ⊙ Wait times are a function of patient through out of the ED through discharge as well as to other departments (ICU, surgery, etc.)



## Case 2: A Tactical-level problem

- ⊙ System: Health care processes in place?
- ⊙ Interactions: Are there spatial relationships between patients and dialysis clinics?
- ⊙ Multilevel: A strategic-level problem, but are other levels involved?
- ⊙ Understanding: Are patient centered-care issues at play here?
- ⊙ Loops: Feedback or feed forward occurring?
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## Q & A

