The Role of Modeling and Simulation in Coordination of Health Care

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Overview

• To address the role of M&S in Coordination of Health Care we ask
  – Why Does US Health Care need Coordination?
  – Ideas for Fixing The Health Care System – Porter’s Value-based Health Care and Pathway-based Coordination

• Then we provide some needed technical background:
  – System Theory and System-of-Systems (SoS)
  – Discrete Event Systems Specification (DEVS) modeling and simulation framework
  – DEVS SoS formalization of Value-based Coordinated Care

• And then present the:
  – Role of the MS4 Modeling and Simulation Environment in implementing and improving Value-based Coordinated Care
Health Care Reform – A Systems Problem

• US healthcare system, the most expensive in the world,
  – Serves 350 million people with no central control (single payer)
  – an assemblage of fragmented, loosely coupled, uncoordinated subsystems embedded in a market economy (Workshop of HC Experts)
  – promotes fee-for-services without reference to the end-to-end quality of care and cost delivered to patients.
• President’s Council advocates that the U.S. health care industry should adopt a systems-engineering approach to improve overall quality and delivery of care
• Improving the health care sector presents a challenge in that the optimization cannot be achieved by sub-optimizing the component systems, but must be directed at the entire system itself.
• An ideal (optimal) health care delivery system will require methods to model large scale distributed complex systems.
US healthcare system consumes 1/3 of Budget. Why?*

- **Medical professionals are smart, work very hard, but are narrowly trained.**
  Example: Clinical trial mindset, control all but variables of interest
  Not trained to cope with complexity of integrating numerous coupled interventions
  Not trained to collaborate in teams

- **System is bad, not the people**
  Doesn't allow them to succeed
  The usual reasons for failure don't apply
  Competition doesn't work: Zero sum - cost shifting

  **Value-based health care is the right goal i.e., value not cost**
  Positive outcome is more critical than efficiency
  Healthier patients, get them recovered faster, with better functionality
  Positive sum - value everyone benefits

- **Value-based purchasing vs cost-based purchasing**

- **Central driver of value improvement is universal outcome measurement**
  Only 2 examples in US: Organ transplants, in vitro fertilization

*Michael Porter on Paving the Way for Value-Based Health Care*
Visualizing the Current State of US Healthcare
Visualizing the Current State of US Healthcare

Interventions

Today's End-to-End Treatment of Medical Conditions

Ideal Care Delivery Value Chain

Faster, Better Treatment at Lower Cost
Vector Dot Product Analogy for Alignment of Service to Value for Client

- Price charged to client
- Projection = actual contribution to value for client
- Mis-alignment of service to value for client (outcome/cost)
- Actual Service is uncontrolled by pay-for-service
- Pay-for-value and competition will necessitate re-orientation
- Direction to value for client

Pay-for-value and competition will necessitate re-orientation.
Need an Organizing Principle

Two working candidates:
• Porter’s Integrated Practice Unit
  – Organization at physicians’ practice level
  – Does not scale
  – Requires too much integration
• Pathways Community HUB Model
  – Coordinated care at community level
  – Pathways provide coordination not integration

So combine both into one organizing concept
• Value to consumer = Outcome/Cost
• Care Delivery Value Chain
• Outcome Measurement Hierarchy
• Pathways Coordination Model
• Monitoring, Tracking, Guiding Individuals – Feedback
• Applicable to clinical and extra-clinical care

Care Delivery Value Chain For Coordinating Interventions

- Integrated/Coordinated interventions oriented around a specific medical condition
- Well-defined sub-segment of Full Cycle of Care
- Care Delivery Value Chain (CDVC)
  - The set and sequence of activities are aligned with value - generally value should increase and cannot decrease, later activities cannot have lesser value than precursors.
  - Taken together, the activities must achieve the desired outcomes
  - The activities have the right scopes to cover the target medical cluster of conditions and to minimally overlap
  - The activities form a coherent whole with seamless handoffs from one to the other – this will ultimately minimize process delays and “dropping the baton”

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Fixing Health Care Systems

• Model Health Care as System of System (SoS)

• Develop Coordination Models for SoS

• Apply DEVS-Based Modeling and Simulation Methodology

• Develop Implementations and applications to demonstrate effectiveness

• Expand scope to other areas in need of similar coordination
SoS Coordination Development Methodology

System of Systems

Abstraction

Simulation Model

Virtual Test

Simulation

component

coordination

System

Abstraction

Coordination Models

Model Continuity

Implementation

RTSync
DEVS-Based SoS Coordination Development Methodology

System of Systems
Abstraction
Simulation Model
Virtual Test
DEVS Pathways
Model Continuity
DEVS Pathways System

Representation by DEVS coupled and atomic models

Simulation
Implementation

DEVS Modeling and Simulation Environments

MS4 Systems provides DEVS-based Integrated Development Environment (IDE)
http://ms4systems.com/

Web-based Pathways System

Static / dynamic Web Pages

Information Database

- Simulator/Coordinator Database
- DEVS Model Database
- Libraries for Calculation/Compare/LogData
- Calculation/Compare/LogData Database
- Libraries for XML

DNL Parser
SES Parser

Web Server
Wymore’s Mathematical System Framework*

- **Composition of Systems** – *constituent systems* and *coupling* specification result in a system with structure and behavior emerging from their interaction.
- **Closure under coupling** – resultant is a well-defined system just like the original components.

*Will show how this can help in design of SoS coordination*

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Discrete Event System Specification (DEVS) Formalism

- **DEVS Atomic and Coupled Models** specify Wymore Systems
- **Composition of DEVS Models** – *component DEVS* and *coupling* result in a DEVS with structure and behavior emerging from their interaction
- **Closure under coupling** – resultant is a well-defined DEVS just like the original components

![Diagram showing DEVS models, coupling specification, and resultant DEVS]
System of Systems (SoS) – composition of systems - component systems have legacy properties e.g., autonomy, belonging, diversity

Coupling has properties e.g., connectivity, coordination

Structural and behavioral properties characterize resulting SoS with properties such as fragmented, competitive, collaborative, coordinated, etc.

DEVS Pathways

• Pathways are event-based control mechanisms that can orchestrate services of disparate providers to achieve a client’s goal.

• A Pathway is a sequence of steps that can check for sub-goal achievement in real-time and progress from step to step only upon confirming such achievement.

• Pathways coordinate actions among multiple users that interact with the client

• Pathways measure, track and monitor individual progress

• Pathways collect and aggregate data to provide analytics for overall supervision and management

• Pathways are dynamic processes and can be combined to accomplish more complex client goals
  – The Pathways Monitor can start up/spawn additional pathways based on
    • time-scheduled actions – active calendar
    • contingent on actions taken or not taken
    • passage of time
    • as a result of data collected during pathway execution
Expression of Pathway as DEVS Atomic Model: 
Instance of Formalization and Implementation

An Atomic Pathways model is a DEVS
AtomicPathway = (X, Y, S, δext, δint, λ, ta)

where
X is the set of inputs;
Y is the set of outputs;
S is the set of sequential states;
δext : Q’ X → S is the external state transition function;
δint : S → S is the internal state transition function;
λ: S → Y is the output function;
ta : S → R[0+ ∪ ∞] is the time advance function;
with Q = { (s, e) | s ∈ S, 0 ≤ e ≤ ta(s) } is the set of total states.

Definition of Set and Functions
X = Answers ∪ { Activate}, Y = Queries ∪ { Activate}
S = { s₀, s₁, s₂, s₃... sₙ } ∪ { Success, Failure, Incomplete, End }
ta(s₀) = ∞
δext(s₀,e, Activate) = s₁
δint(sᵢ) = sᵢ₊₁ ta(sᵢ) = 0 λ(sᵢ) ∈ Queries
δext(sᵢ₊₁,e, ans) = sᵢ₊₂ for ans ∈ Answers
ta(sᵢ₊₁) = Tᵢ₊₁, δint(sᵢ₊₁) = Incomplete
δext(sₙ,e, ans) ∈ { Success, Failure } ta(sₙ) = Tₙ, δint(sₙ) = Incomplete

ta(Success) = 0 λ(Success) = Activate
δint(Success) = End ta(End) = ∞
ta(Failure) = ∞ ta(Incomplete) = ∞
Example: Single Q&A Pathway Model
Pathways for Coordination

• Can design pathways to represent coordination processes.
• Coupling atomic pathway models can coordinate the behavior of multiple concurrent pathways.
• DEVS closure under coupling will assure that the resultant is a DEVS model.
• More than that, the resultant is also expressible as an atomic pathway model, establishing closure of pathway models under coupling.
• The following property is proved for such closure:
  • Finite Termination Property: For any pathway model, there is a finite time $T$, such that the model or all its components reach, and passivate, in any one the three types of states: Success, Failed, or Incomplete within time $T$ after initialization.
Pathway Coordination Example Application:
Drop-off of Untreated Patients at Stages of Engagement in HIV Care

![Bar chart showing the spectrum of engagement in HIV care with numbers of individuals at different stages: 1,106,400 HIV-infected, 874,056 HIV-diagnosed, 655,542 linked to HIV care, 437,028 retained in HIV care, 349,622 on antiretroviral therapy, 262,217 adherent/undetectable.]

Pathways Coordination of HIV-AIDS Continuity of Care

- Clinical Domain
  - 1: Diagnose HIV
  - 3: Treatment
- Extra-Clinical Domain
  - 2: Engage in Care
  - 4: Suppression

Coupled Model Pathway

- Formulate CoC as CDVC
- Coordination Via cross-organization Pathways

• Pathways for each Stage assure patient is effectively managed through the CDVC
• Coupled Model for Coordination of Stages
  - Completion of a pathway activates next pathway
  - Individual is reliably handed off from one to the next
  - Coupling is predicated on Health Information Network to be in existence
Role of M&S in Coordination of Health Care: Using MS4 Me to support Pathways Design and Implementation

State Designer of Pathways

System Entity Structure (SES) specification of HIV-AIDS Continuity of Care

SES Tree portrayal
Menu Choices Pane

Pruning selections

Credit accumulated so far – can be used for making selections Toward improvement

Coupled models tried so far

Credit computation

DEVSPathwaySim cont’d

Pruning Process

Select a SES Document: CarePathway

Root Entity: CarePathway

Specialization Table

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<tr>
<td></td>
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Pathway System

Outcome

Total Activity

Pathway System

Outcome

Total Activity

Select a Coupled Pathway: cseo@ms4systems.com:CareForV3:test8

Test Result of cseo@ms4systems.com:CareForV3:test8's Components

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<td>SuppressionSlot_Method1</td>
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The Unique Features of DEVSPathwaySim

DEVSPathwaySim is built on the MS4Me Modeling and Simulation Platform and offers unique features based on this layering:

– Concurrent pathways can operate in series, parallel or combinations

– Pathways measure outcome events of SoS simultaneously with activity in the system components
  • This information is correlated to provide ratings of component value, i.e., ability to participate in creating outcome value
  • component ratings can inform combinatorial selection to improve system outcome value
Summary

• Health Care Reform is usefully viewed as a Systems Problem
• Porter’s Value-based Health care and CDVC within a more inclusive Pathways Coordinated Care framework provides needed coordination
• Formalized this framework using System-of-Systems (SoS) theory expressed in the DEVS Modeling and Simulation methodology
• MS4 Modeling and Simulation Environment based on DEVS supports design and implementation in a systems engineering approach
Take-aways

• In complex SoSs, what's measured can be improved:
  In a competitive environment it will be improved.
  – DEVS pathways coordinate and measure value at SoS level.
  – Activity-based credit assignment (ACA) enables ratings of component system for contribution to value.

• SES with ACA support searching through combinatorial spaces for incrementally improved SoSs.

• Future research challenge: how to use M&S to enable Health care SoS (and others) to become true self-learning systems!
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