Systems science modeling for implementation research: An application to tobacco smoking cessation for persons with serious mental illness

Tak Igusa, PhD
Professor, Center for Systems Science & Engineering

Gail L. Daumit, MD, MHS
Samsung Professor of Medicine, Johns Hopkins University School of Medicine
Director, Johns Hopkins NIMH ALACRITY Center
People with serious mental illness die 10-20 years earlier than the overall population, largely driven by high rates of cardiovascular disease and other physical health conditions.

Through research, training, and community partnerships, the Johns Hopkins ALACRITY Center seeks to speed translation of effective interventions to improve physical health and reduce premature mortality among people with serious mental illness into everyday practice.

Funded by the National Institute of Mental Health (P50115842)
ACHIEVE-D: Adapting an evidence-based weight loss intervention and testing strategies to increase implementation in community mental health programs

IMPACT: Promoting evidence-based tobacco smoking cessation treatment in community mental health clinics

RHYTHM: Using an innovative quality improvement process to increase delivery of evidence-based cardiovascular disease risk factor care in community mental health organizations
ALACRITY Organizational structure

External Advisory Board
External research experts

Administrative Core
Center Leadership

Internal Steering Committee
Internal university leaders

Stakeholder Advisory Board
Key practice & policy stakeholders

Center Executive Committee
Center leadership, Core leadership, and research project leadership

Training Core
Center members with expertise in developing and disseminating trainings for researchers and practitioners

Community Engagement Core
Center members with expertise in community engagement

Methods Core
Transdisciplinary teams of Center members with methods expertise

Intervention Development & Adaptation Sub-Core

Measurement Sub-Core

Implementation Strategy Development Sub-Core

Data Collection Sub-Core

Partnership, Recruitment & Retention Sub-Core

Data Management and Analysis Sub-Core

Healthcare Financing and Policy Sub-Core

Implementation Research Projects
Project 1: Behavioral weight loss intervention
Project 2: Smoking cessation treatment
Project 3: Guideline-concordant care “bundle” for hypertension, dyslipidemia, and diabetes mellitus
ALACRITY Systems Science Core Members

FACULTY

► Gail L. Daumit, Division of General Internal Medicine
► Emma E. McGinty, Dept Health Policy & Management
► Elizabeth A. Stuart, Dept Mental Health
► Nae-Yuh Wang, Division of General Internal Medicine
► Tak Igusa, Center for Systems Science & Engineering (CSSE)

PHD STUDENTS

► Wanyu Huang, Todd Chang, CSSE
► Tingting Ji, Hong Kong Polytechnic University
EBP used in all examples: IDEAL
A smoking cessation program for persons with serious mental illness
Implementation of a smoking cessation intervention

Implementation agency
- Training, Education, Implementation guidance
- Target: Patients with SMI
- Providers
- Intervention agent: Counseling, Prescriptions
- Prescribers

CLINICAL SITE
- Implementation processes
  - Integration with clinical work
  - Leveraging networks
  - Managing attitudes

Implementation outcomes
- Adoption
- Appropriateness
- Fidelity
- Cost

Policy options
1. Stepped care therapy or tailored care therapy
2. Fee-for-service or outcome-based reimbursements

Payer agent
- Administrative service organization (e.g., Optum Maryland)

Policy makers
- State agencies (e.g., Behavioral Health Administration and Medicaid office)

Clinical outcomes
- Quit rate

Why systems science?

**STRENGTHS**

- Systems science models can:
  - Simulate implementation processes including multiple interacting components
  - Integrate expert knowledge + data

**WEAKNESSES & MITIGATION STRATEGY**

- High data requirements
  - Rely on parameters from related studies
  - Divulge assumptions
  - Focus on sensitivity studies (what-if scenarios)

- Complex simulation result
  - Explain in terms of implementation frameworks

Stepwise procedure for developing systems science models

- Articulate the **research question**

- Select the **systems science model**

- **Formulate the model**

- **Run the model** and explore possible emergent patterns of behavior.

- Use the **model outputs** to guide implementation plans.

Huang, et al (2021)
Model selection

- ABMs with Multi-Level Interactions
- ABMs with Social Networks
- ABMs with Complex Behavioral Rules
- ABMs with Simple Interacting Agents
- Microsimulation
- Population-Averaged Methods

Input requirements

- Site leadership, external factors
- Patient, provider networks
- Detailed interactions and behaviors
- Patient-provider interactions
- Patient-centric model

Huang, et al (2021)
Implementation of a smoking cessation intervention

Implementation outcomes
- Adoption
- Appropriateness
- Fidelity
- Cost

Clinical outcomes
- Quit rate

Policy options
1. Stepped care therapy or tailored care therapy
2. Fee-for-service or outcome-based reimbursements

Implementation processes
- Integration with clinical work
- Leveraging networks
- Managing attitudes

CLINICAL SITE
- Prescriptions
- Counseling
- Patients with SMI
- Providers

Implementation agency
- Training, Education, Implementation guidance

Payer agent
- Administrative service organization (e.g., Optum Maryland)

Policy makers
- State agencies (e.g., Behavioral Health Administration and Medicaid office)

State agencies
(e.g., Behavioral Health Administration and Medicaid office)

Prescribers

Providers

Counseling

Target

Microsimulation of individual willingness-to-quit transitions in a smoking cessation program

The material in this video is subject to the copyright of the owners of the material and is being provided for educational purposes under rules of fair use for registered students in this course only. No additional copies of the copyrighted work may be made or distributed.
What are the processes within individual patients that should be closely monitored?
Implementation of a smoking cessation intervention

- Adoption
- Appropriateness
- Fidelity
- Cost

Implementation processes
- Integration with clinical work
- Leveraging networks
- Managing attitudes

Implementation outcomes
- Adoption
- Appropriateness
- Fidelity
- Cost

Policy options
1. Stepped care therapy or tailored care therapy
2. Fee-for-service or outcome-based reimbursements

Clinical outcomes
Quit rate

Target: Patients with SMI

Providers
- Counseling
- Prescriptions

Prescribers

Administrative service organization (e.g., Optum Maryland)

State agencies (e.g., Behavioral Health Administration and Medicaid office)

CLINICAL SITE

Policy makers

Model selection

- ABMs with Multi-Level Interactions
- ABMs with Social Networks
- ABMs with Complex Behavioral Rules
- ABMs with Simple Interacting Agents
- Microsimulation
- Population-Averaged Methods
- Patient-centric model

Huang, et al (2021)
Model formulation: Levels of willingness-to-quit

**Microsimulation model**
- Markov process
- Transition probabilities between internal states

**Factors that influences change of smoking status**
- Smoking history
- Susceptibility
- Willingness to quit
- Peer support
- Pharmacotherapy
- Counseling

Markov states

Smoking Status vs Time

Smoking Status

Markov Transition Map
Willingness-to-quit

- high
- medium
- low

Goal: Smokeless

Relationships between Markov states and willingness-to-quit

Smoking Status vs Time

Willingness-to-quit vs Time

Markov Transition Map
Willingness-to-quit

- high
- medium
- low

Goal: quit smoking

Time

W-T-Q: Willingness-to-quit
- high
- medium
- low
MODEL FORMULATION

Levels of willingness-to-quit

• Markov transition matrix for individual i’s willingness-to-quit

\[
\begin{pmatrix}
  p_1^i & p_2^i & 1 - p_1^i - p_2^i \\
  p_3^i & p_1^i & p_2^i \\
  1 - p_1^i - p_3^i & p_3^i & p_1^i
\end{pmatrix}
\]

• We assumed that the transition probability is based on baseline covariates $X_i$ for patient $i$ using the logit function

\[
p_k^i = \frac{1}{1 + \exp(-\beta_{1,k} - \beta_{2,k}X_i)}
\]

Example 1: IDEAL, A smoking cessation program for persons with serious mental illness

**MODEL OUTPUTS**

Explore the associations between lasso-selected variables and agents’ abstinent status

<table>
<thead>
<tr>
<th>Variables</th>
<th>$\beta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>0.73</td>
</tr>
<tr>
<td>Caucasian</td>
<td>98.85</td>
</tr>
<tr>
<td>Schizophrenia</td>
<td>-0.80</td>
</tr>
<tr>
<td>Bipolar disorder</td>
<td>-1.84</td>
</tr>
<tr>
<td>Depression</td>
<td>2.08</td>
</tr>
<tr>
<td>Employment</td>
<td>46.53</td>
</tr>
<tr>
<td>BASIS-24 score</td>
<td>-1.81</td>
</tr>
<tr>
<td>Change in w-t-q</td>
<td>1.07</td>
</tr>
</tbody>
</table>

Time

Willingness-to-quit vs Time

W-T-Q

high

medium

low

Smoking Status vs Time

Smoking Status

Goal:
References

Agent-based simulation of peer influence in smoking cessation intervention program
Are individual patients affected by peer influence in group sessions?
Implementation of a smoking cessation intervention

Implementation outcomes
- Adoption
- Appropriateness
- Fidelity
- Cost

Policy options
1. Stepped care therapy or tailored care therapy
2. Fee-for-service or outcome-based reimbursements

Clinical outcomes
- Quit rate
Model selection

- ABMs with Multi-Level Interactions
- ABMs with Social Networks
- ABMs with Complex Behavioral Rules
- ABMs with Simple Interacting Agents
- Microsimulation
- Population-Averaged Methods

Patient, provider networks

Patient-provider interactions

Huang, et al (2021)
Group counseling sessions

Mean effect from peer influence is positive

Stronger influence from those who smoke less

Non-linear regression model

\[ Y_i(t) = \text{smoking status of patient } i \text{ at time } t \]

\[ \bar{Y}(t) = \text{group mean} \]

\[ Y_i(t + 1) - Y_i(t) = \beta_0 + \beta_{\text{patient below group mean}} \times (\bar{Y}(t) - Y_i(t)) \]

\[ Y_i(t + 1) - Y_i(t) = \beta_0 + \beta_{\text{patient above group mean}} \times (\bar{Y}(t) - Y_i(t)) \]

Regression coefficients for group effects

<table>
<thead>
<tr>
<th>Group session type</th>
<th>Group effects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Individual <strong>below</strong> group average</td>
</tr>
<tr>
<td>Overall (N=1184)</td>
<td>0.0821</td>
</tr>
<tr>
<td>Motivational Enhancement (N=93)</td>
<td>0.154</td>
</tr>
<tr>
<td>Smoking Cessation (N=862)</td>
<td>-0.0127</td>
</tr>
<tr>
<td>Relapse Prevention (N=229)</td>
<td>-0.0184</td>
</tr>
</tbody>
</table>

Other group members smoked much less than me!

Now I’m much closer to the average level. Keep going!
Simulation of smoking cessation program with and without group sessions
Simulations including transitions between group session types

- Multiple groups
- Assignment to improve site performance
References

Agent-based simulation of implementation barriers and strategies
How do implementation strategies affect site processes?
Implementation of a smoking cessation intervention
Model selection

Huang, et al (2021)

- ABMs with Multi-Level Interactions
- ABMs with Social Networks
- ABMs with Complex Behavioral Rules
- ABMs with Simple Interacting Agents
- Microsimulation
- Population-Averaged Methods

Patient, provider networks
Detailed interactions and behaviors
Patient-provider interactions

Input requirements
Model selection

- ABMs with Multi-Level Interactions
- ABMs with Social Networks
- ABMs with Complex Behavioral Rules
- ABMs with Simple Interacting Agents
- Microsimulation
- Population-Averaged Methods

Patient, provider networks
Detailed interactions and behaviors
Patient-provider interactions

Huang, et al (2021)
Links between determinants, implementation strategies, and implementation outcomes *(Lewis, et al. 2021)*

<table>
<thead>
<tr>
<th>Determinant</th>
<th>Implementation strategy</th>
<th>Mechanism</th>
<th>Implementation outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provider knowledge deficit</td>
<td>Education (provision of information)</td>
<td>Awareness-building, knowledge-acquisition</td>
<td>Feasibility, acceptability, appropriateness, adoption</td>
</tr>
<tr>
<td>Provider skill deficit</td>
<td>Training (teaching and practice with corrective feedback)</td>
<td>Skill acquisition, refinement, mastery</td>
<td>Fidelity to EBP</td>
</tr>
<tr>
<td>Provider view EBP unfavorably</td>
<td>Audit and feedback provision of descriptive social norms indicating peer use of EBP</td>
<td>Social pressure/norms</td>
<td>Adoption</td>
</tr>
<tr>
<td>Competing clinical demands</td>
<td>Leadership training</td>
<td>Growing leadership support/perseverance</td>
<td>Adoption, sustainability</td>
</tr>
</tbody>
</table>
Training

PROVIDER
Knowledge/skills

PATIENT
Willingness To Quit

<table>
<thead>
<tr>
<th>Determinant</th>
<th>Implementation strategy</th>
<th>Mechanism</th>
<th>Implementation outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge deficit</td>
<td>Education</td>
<td>Awareness-building</td>
<td>Acceptability</td>
</tr>
<tr>
<td>Skill deficit</td>
<td>Training</td>
<td>Skill acquisition</td>
<td>Fidelity to EBP</td>
</tr>
<tr>
<td>Unfavorable view</td>
<td>Audit and feedback</td>
<td>Social pressure/norms</td>
<td>Adoption</td>
</tr>
<tr>
<td>Clinical demands</td>
<td>Leadership training</td>
<td>Leadership support</td>
<td>Sustainability</td>
</tr>
<tr>
<td>Determinant</td>
<td>Implementation strategy</td>
<td>Mechanism</td>
<td>Implementation outcome</td>
</tr>
<tr>
<td>------------------------</td>
<td>-------------------------</td>
<td>-----------------------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>Knowledge deficit</td>
<td>Education</td>
<td>Awareness-building</td>
<td>Acceptability</td>
</tr>
<tr>
<td>Skill deficit</td>
<td>Training</td>
<td>Skill acquisition</td>
<td>Fidelity to EBP</td>
</tr>
<tr>
<td>Unfavorable view</td>
<td>Audit and feedback</td>
<td>Social pressure/norms</td>
<td>Adoption</td>
</tr>
<tr>
<td>Clinical demands</td>
<td>Leadership training</td>
<td>Leadership support</td>
<td>Sustainability</td>
</tr>
</tbody>
</table>
**View of the EBP**

- **PROVIDER**
  - Knowledge/skills
  - Clinical demands
  - Unfavorable view

- **PATIENT**
  - Willingness To Quit

**Determinant** | **Implementation strategy** | **Mechanism** | **Implementation outcome**
--- | --- | --- | ---
Knowledge deficit | Education | Awareness-building | Acceptability
Skill deficit | Training | Skill acquisition | Fidelity to EBP
Unfavorable view | Audit and feedback | Social pressure/norms | Adoption
Clinical demands | Leadership training | Leadership support | Sustainability
## Determinant Implementation strategy Mechanism Implementatio n outcome

<table>
<thead>
<tr>
<th>Determinant</th>
<th>Implementation strategy</th>
<th>Mechanism</th>
<th>Implementation outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge deficit</td>
<td>Education</td>
<td>Awareness-building</td>
<td>Acceptability</td>
</tr>
<tr>
<td>Skill deficit</td>
<td>Training</td>
<td>Skill acquisition</td>
<td>Fidelity to EBP</td>
</tr>
<tr>
<td>Unfavorable view</td>
<td>Audit and feedback</td>
<td>Social pressure/norms</td>
<td>Adoption</td>
</tr>
<tr>
<td>Clinical demands</td>
<td>Leadership training</td>
<td>Leadership support</td>
<td>Sustainability</td>
</tr>
</tbody>
</table>
### Determinant Implementation Strategy Mechanism Implementation Outcome

<table>
<thead>
<tr>
<th>Determinant</th>
<th>Implementation Strategy</th>
<th>Mechanism</th>
<th>Implementation Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge deficit</td>
<td>Education</td>
<td>Awareness-building</td>
<td>Acceptability</td>
</tr>
<tr>
<td>Skill deficit</td>
<td>Training</td>
<td>Skill acquisition</td>
<td>Fidelity to EBP</td>
</tr>
<tr>
<td>Unfavorable view</td>
<td>Audit and feedback</td>
<td>Social pressure/norms</td>
<td>Adoption</td>
</tr>
<tr>
<td>Clinical demands</td>
<td>Leadership training</td>
<td>Leadership support</td>
<td>Sustainability</td>
</tr>
</tbody>
</table>
Agent-Based Simulation

Initial attitudes towards the EBP

Attitudes towards the EBP after 30 sessions

Initial willingness to quit

Final willingness to quit
Training

- PROVIDER
  - Knowledge/skills
  - Clinical demands
  - Unfavorable view

- PATIENT
  - Willingness To Quit

Graphs show trends in provider attitude and patient willingness to quit over time.
Outcomes

feedback

Training

PROVIDER

Knowledge/skills

Clinical demands

Unfavorable view

PATIENT

Willingness To Quit

Number of sessions

Provider Attitude

Patient Willingness to Quit
References

Agent-based simulation of the impacts of Medicaid policies
Research question

What are the impacts of Medicaid policies on the implementation of a smoking cessation intervention?
Implementation of a smoking cessation intervention

Implementation outcomes
- Adoption
- Appropriateness
- Fidelity
- Cost

Clinical outcomes
- Quit rate

Policy options
1. Stepped care therapy or tailored care therapy
2. Fee-for-service or outcome-based reimbursements

Implementation processes
- Integration with clinical work
- Leveraging networks
- Managing attitudes

Target
- Patients with SMI

Providers
- Counseling
- Prescriptions

Prescribers

Payer agent
- Administrative service organization (e.g., Optum Maryland)

Policy makers
- State agencies (e.g., Behavioral Health Administration and Medicaid office)

Implementation agency
- Training, Education, Implementation guidance

CLINICAL SITE

Example 3: TIRUMPH, A smoking cessation program for persons with serious mental illness - Medicaid policies

MODEL SELECTION

- ABMs with Multi-Level Interactions
- ABMs with Social Networks
- ABMs with Complex Behavioral Rules
- ABMs with Simple Interacting Agents
- Microsimulation
- Population-Averaged Methods

- Site leadership, external factors
- Patient, provider networks
- Detailed interactions and behaviors
- Patient-provider interactions
- Patient-centric model

Huang, et al (2021)
Stepped therapy

Determinant | Implementation strategy | Mechanism | Implementation outcome
---|---|---|---
Knowledge deficit | Education | Awareness-building | Appropriateness, acceptability
Skill deficit | Training | Skill acquisition | Fidelity to EBP
Unfavorable view | Audit and feedback | Social pressure/norms | Adoption
Clinical demands | Leadership training | Leadership support | Sustainability

Prescribers' medication-use strategy

- NRT
- Bupropion
- Varenicline

Use low-cost medication first, if fail, then may use high-cost medication.
Tailored therapy requires additional work

-> high competing clinical demands
Policy lever test 1: Stepped care therapy restriction

**INNER SETTING**

- Providers
- Patients
- Counseling + Medication

- Medication use strategy
  - ability to adopt appropriate treatment

- Readiness to quit

**OUTER SETTING**

Policy lever 1: Stepped care therapy restriction

**Stepped care therapy**

**Pros:**
- Lower time cost
- Less training requirement

**Cons:**
- Lower patient outcomes
- Lower efficiency

**Tailored care therapy**

**Pros**
- Higher patient outcomes

**Cons**
- Higher time cost
- Higher training requirement
- More workload

ABM for simulating the implementation process

### Determinant | Implementation strategy | Mechanism | Implementation outcome
--- | --- | --- | ---
Knowledge deficit | Education | Awareness-building | Appropriateness, acceptability
Skill deficit | Training | Skill acquisition | Fidelity to EBP
Unfavorable view | Audit and feedback | Social pressure/norms | Adoption
Clinical demands | Leadership training | Leadership support | Sustainability

**Prescribers' medication-use strategy**
- NRT
- Bupropion
- Varenicline

**Low-cost**

**Stepped therapy**

**PREScriber**
Knowledge on medication use

**PATient**
Willingness To Quit

---

**Figure:**
- #Patients (Stepped)
- Graph showing step 1 and step 2 with a decrease in patients over weeks.
- Initial number of patients at step 1: 110, at step 2: 50, at week 73: 8.8

---

**Table:**

<table>
<thead>
<tr>
<th>Determinant</th>
<th>Implementation strategy</th>
<th>Mechanism</th>
<th>Implementation outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge deficit</td>
<td>Education</td>
<td>Awareness-building</td>
<td>Appropriateness, acceptability</td>
</tr>
<tr>
<td>Skill deficit</td>
<td>Training</td>
<td>Skill acquisition</td>
<td>Fidelity to EBP</td>
</tr>
<tr>
<td>Unfavorable view</td>
<td>Audit and feedback</td>
<td>Social pressure/norms</td>
<td>Adoption</td>
</tr>
<tr>
<td>Clinical demands</td>
<td>Leadership training</td>
<td>Leadership support</td>
<td>Sustainability</td>
</tr>
</tbody>
</table>
### Tailored therapy

#### Training for tailored therapy

<table>
<thead>
<tr>
<th>Determinant</th>
<th>Implementation strategy</th>
<th>Mechanism</th>
<th>Implementation outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge deficit</td>
<td>Education</td>
<td>Awareness-building</td>
<td>Appropriateness, acceptability</td>
</tr>
<tr>
<td>Skill deficit</td>
<td>Training</td>
<td>Skill acquisition</td>
<td>Fidelity to EBP</td>
</tr>
<tr>
<td>Unfavorable view</td>
<td>Audit and feedback</td>
<td>Social pressure/norms</td>
<td>Adoption</td>
</tr>
<tr>
<td>Clinical demands</td>
<td>Leadership training</td>
<td>Leadership support</td>
<td>Sustainability</td>
</tr>
</tbody>
</table>

#### PROVIDER

- Knowledge/skills

#### IMPLEMENTATION

- Attend training
  - Preparedness work
  - Med-related work
  - Time for sessions

#### OUTCOME

- Fidelity

---

[Image of a chart showing training time per provider and fidelity]

56
Determinant | Implementation strategy | Mechanism | Implementation outcome
---|---|---|---
Knowledge deficit | Education | Awareness-building | Appropriateness, acceptability
Skill deficit | Training | Skill acquisition | Fidelity to EBP
Unfavorable view | Audit and feedback | Social pressure/norms | Adoption
Clinical demands | Leadership training | Leadership support | Sustainability

Tailored therapy

PROVIDER
Clinical demands

PATIENT
#Patients with treatment
#Delayed treatment

Attend training

Providers' time-use strategy

Preparedness work

Med-related work

Time for sessions

Clinical demands

PROVIDER

Time-use strategy

IND-sessions
PREP-IND
MEDI-WORK

Avg.time / patient

0.0973
0.0
73.8

0
57
Cost effectiveness of Medicaid payer

Tailored care is cost effective
Cost effectiveness of Medicaid payer

Stepped care is cost effective
Sensitivity analyses results

- Stepped care therapy → sites with more patients
  → sites with limited human resources

- Tailored care therapy → sites with less competing clinical demands
  → sites with more training investment

- Barrier for choosing tailored care: heavy workload of health providers
Simulation of the implementation processes using NetLogo

Wilensky (1999); Macal & North (2005)


This presentation was supported by the Johns Hopkins ALACRITY Center through Grant No. P50 MH115842 (Center to Accelerate Translation of Interventions to Decrease Premature Mortality in SMI) from the National Institutes of Health.