Application of Agent-based Modelling for Health Promotion

Yong Yang
School of Public Health
University of Memphis
yyang15@memphis.edu

2017 Art & Science of Health Promotion Conferences
Conflicts of interest

No actual, potential or perceived conflict of interest for myself or spouse/partner.
Agenda

1. Introduction of agent-based modelling

2. A simple model for the access to healthy food

3. A model for children’s active travel to school

4. Discussions
Introduction of agent-based modelling
“Maybe pushing on that wall to the right will give some space.”
“Oops!”
Systems thinking is the process of understanding how things influence one another within a whole.

- The whole picture
- Interactions between parts
- Emergent property
- Feedback
- Delay
- ...

Systems thinking and key components
Agent-based model (ABM)

A class of computational models: an bottom-up modeling approach for simulating the actions and interactions of a number of agents, agents with their environment, and various environmental features to gain understanding at the whole system level

https://www.youtube.com/watch?v=A4Q5A2ZNpxk [to 2:40], from Bill Rand, Santa Fe Institute
Empirical literature, existing theory, research, and data sources

Proposed theories for behavior at the agent level

Patterns of emergent behavior at higher levels

How well does ABM reproduce observed patterns?

Agent-based modelling

From *Agent-Based and Individual-Based Modeling: A Practical Introduction* (2011) by Steven F. Railsback and Volker Grimm, Page 245
Key properties of ABM

• Heterogeneous: agents allowed to differ from one another on important characteristics
• Spatial: agents are located in some explicitly defined space
• Interactive: agents can interact locally with one another and their environment
• Bounded rationality: agents are assumed to have imperfect knowledge
• Dynamic: models are recursive, allowed to change non-linearly and exhibit non-equilibrium

Luke and Stamatakis, 2012
Why ABM is a promising approach in public health?

• The complexity of public health problems
  • For example, a health care system can be defined as a set of connected or interdependent parts or agents—including caregivers and patients—bound by a common purpose and acting on their knowledge. Health care is complex because of the great number of interconnections within and among small care systems. [Institute of Medicine, 2001]
  • Health behavior change: non-linear, sensitive to initial conditions, highly variable, difficult to predict, occurs within a complex adaptive system with multiple components, where results are often greater than the sum of their parts. [Resnicow and Scott, 2008]

• Computing power
• Accumulated knowledge
• Data
ABM Applications in Public Health

• From 2003 to 2014, 22 published ABM on non-communicable diseases and risk factors, as reviewed by Nianogo, et ta. (2015)

• Diseases
  • Obesity, diabetes, hypertension, diabetic retinopathy, vision loss, and sclerosis

• Health behaviors
  • Physical activities, walking, drinking, diet, and smoking

• Health care
  • Colorectal cancer screening tests, diabetes-type 1 management, and vitamin therapy
A simple model for the access to healthy food
Tools for ABM

• Object-oriented languages
  • Objects, attributes, methods

• Tools for ABM: for more information

• NetLogo, by Northwestern University
  • Free, and open source.
  • A large library of sample models
  • [https://ccl.northwestern.edu/netlogo](https://ccl.northwestern.edu/netlogo)
Access to healthy food

- Limited access to healthy foods is a risk factor of obesity and many chronic diseases
- A justice issue: low-income neighborhoods tend to lack healthy food
- Low-income groups tend to have smaller activity space

Food desert: an area where a substantial number or share of residents has low access to a supermarket or large grocery store
Modelling the access to healthy food

• Basic assumption: distance is the only determinant
  • Where are healthy foods? distribution pattern?
  • Could far a person could travel for food?

• Outcome: the percent \((P)\) of people who have at least one healthy food shop within their travel distance

A toy model illustrating the potential of ABM instead of solving a empirical problem
Step 1: a basic model

- Model description
  - Within a fixed area, or a city (50 miles * 50 miles)
    - A number of people are randomly distributed
    - A number of shops (for healthy food) are randomly distributed
  - A person could travel certain distance for healthy food

- Model demo

- Explore the combination of shop density and travel distance
However, this results could be computed using a simple mathematical formula.
Step 2: spatial pattern and heterogeneity

• Spatial pattern: shops are more likely to locate in city center

• A variation of travel distance among people, with a uniform distribution between 5 and 20 miles

• Minor improvements
  • Size and color of shops
  • Plot of \( P \) over time
At individual level, the probability of access to healthy shop

- Travel distance
- Household’s distance to city center

A logistic analysis

Access (true) = distance to center, travel distance

Results

<table>
<thead>
<tr>
<th>Distance to center</th>
<th>-0.15</th>
<th>&lt;.0001</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel distance</td>
<td>0.56</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

*Disparity of the access to healthy food?*
Step 3: various shopping behaviors

• If more than one shops within the travel distance, which one to choose?
  • Choose the one with the shortest distance
  • Choose the one with the most visitors
  • Choose the one with the least visitors (for fast service?)
Step 4: movements

- A shop with no visitors will move to another location
- A person with no access to shop will move to another location
Reflections

A stepwise process

1. Travel distance and number of shops
2. Spatial pattern and heterogeneity
3. Various shopping behaviors
4. Movement

We could add more

- More factors from multiple levels
- More properties for shops and persons
- More complicated shopping behaviors
- More dynamic interactions
Several published ABMs for diet

• Auchincloss, et al. An Agent-Based Model of Income Inequalities in Diet in the Context of Residential Segregation. AJPM, 2011
• Zhang, et al., Impact of Different Policies on Unhealthy Dietary Behaviors in an Urban Adult Population: An Agent-Based Simulation Model. AJPH, 2014
• Blok, et al., Reducing Income Inequalities in Food Consumption: Explorations With an Agent-Based Model. AJPM, 2015
Agent-based Modeling for Children’s Active Travel to School
Active travel to school (ATS) has multiple benefits:

- Decrease traffic congestion and air pollution.
- A substantial portion of children’s overall physical activity.
- Associate with higher overall physical activity.
- Promote healthy life styles which may be maintained into adulthood.
Children’s travel modes to school

From McDonald, 2007

• Today fewer than 15% US children and adolescents walk or bicycle to school

Concurrently, rates of obesity among children (6-11 years) and adolescents (12-19 years) have increased from 4.2% and 4.6% to 19.6% and 18.1%, respectively [CDC 2012].

Figure 1. Standardized\(^a\) mode shares for trips to school.
\(^a\)Standardized to 2001 age and race distribution. Error bars represent the 95% confidence interval.
Why agent-based modeling?

• Study on active travel
  • Various travel patterns
  • Influenced by multiple factors at multiple levels
  • Interactions between persons
  • Interactions between persons and environments
  • Spatial patterns of environmental factors
  • ...

• Agent-based modeling
  • “Bottom-up” approach
  • Dynamic interaction and feedback over time
  • ...

28
Research Aims

• To explore related features, with focus on the distance to school and traffic safety

  According to CDC, barriers to ATS among US children include distance to school, traffic-related danger, weather, and crime.

• To evaluate intervention strategies walking school bus (WSB)

  The WSB is a program in which children walk to school in groups led by adults along a planned route with designated meeting places (i.e., “bus stops”) where other children join in. The primary goal is to allow children to actively and safely commute to school.
# Framework

<table>
<thead>
<tr>
<th>Level</th>
<th>Factors in the model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social environment</td>
<td>✓ Crime</td>
</tr>
<tr>
<td>Built environment</td>
<td>✓ Traffic safety</td>
</tr>
<tr>
<td></td>
<td>✓ Public transportation</td>
</tr>
<tr>
<td></td>
<td>✓ Land use density</td>
</tr>
<tr>
<td></td>
<td>✓ Land use mix</td>
</tr>
<tr>
<td>Organization/Policy (School)</td>
<td>✓ Size</td>
</tr>
<tr>
<td></td>
<td>✓ Location</td>
</tr>
<tr>
<td></td>
<td>✓ Catchment policy</td>
</tr>
<tr>
<td></td>
<td>✓ School bus system</td>
</tr>
<tr>
<td></td>
<td>✓ School’s norm towards ATS</td>
</tr>
<tr>
<td></td>
<td>✓ ATS school policies</td>
</tr>
<tr>
<td>Interpersonal</td>
<td>✓ Social network of the child</td>
</tr>
<tr>
<td></td>
<td>✓ Parent’s attitude towards ATS, concern on traffic safety, and concern on crime in neighborhood</td>
</tr>
<tr>
<td>Individual/Intrapersonal</td>
<td>✓ Child’s age, gender, habit of school travel, and attitude towards ATS</td>
</tr>
<tr>
<td></td>
<td>✓ Family’s socioeconomic status and car ownership</td>
</tr>
<tr>
<td></td>
<td>✓ Parents’ employment</td>
</tr>
<tr>
<td></td>
<td>✓ The distance to school</td>
</tr>
</tbody>
</table>
Entities in the model

- City: grid space
- Four schools
- 3000 households: each household has a value of safety concern towards child’s walking to travel
- 3000 Child: each has a value of attitude towards walking to school
Baseline scenario
Child’s travel mode choice

A child will walk if both the conditions below are met:

\[ S_t > C_t \]
\[ A_w + P_d > 1 \]

Where
- \( S_t \) is the mean traffic safety of all the cells along the route,
- \( C_t \) is the household’s concern towards traffic safety,
- \( A_w \) is child’s attitude towards walking,
- \( P_d \) is the probability of walking given the distance to the school,
- \( d \) is the distance from household to school,
- \( \beta \) is the distance decay parameter.

\[ P_d = e^{-\beta d} \]
Two dynamic processes

• A child’s attitude is influenced by other children in the same school

  Supported by studies showing the influence of peers and friends on children’s physical activity (Smith 1999; Jago, Macdonald-Wallis et al. 2011; Salvy, de la Haye et al. 2012; Maturo and Cunningham 2013)

• Road safety is influenced by the number of walkers on the road

Calibration

Baseline scenario was calibrated against 2009 NHTS data.

Percentage of children who walk to school by distance, result from 20 simulations on baseline scenario

Percentage of students who usually walk to school by distance, based on 2009 National Household Travel Survey (McDonald, 2011)

<table>
<thead>
<tr>
<th>Miles</th>
<th>Mean</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.25</td>
<td>64.3</td>
<td>50.0</td>
<td>75.4</td>
</tr>
<tr>
<td>0.25-0.5</td>
<td>38.2</td>
<td>33.5</td>
<td>43.6</td>
</tr>
<tr>
<td>0.5-1</td>
<td>16.6</td>
<td>14.9</td>
<td>18.4</td>
</tr>
<tr>
<td>1-2</td>
<td>5.4</td>
<td>4.5</td>
<td>6.6</td>
</tr>
<tr>
<td>&gt;=2</td>
<td>1.2</td>
<td>0.4</td>
<td>3.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Miles</th>
<th>Elementary</th>
<th>Middle</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.25</td>
<td>53.1</td>
<td>65.5</td>
</tr>
<tr>
<td>0.25-0.5</td>
<td>25.5</td>
<td>49.9</td>
</tr>
<tr>
<td>0.5-1</td>
<td>13.9</td>
<td>18.5</td>
</tr>
<tr>
<td>1-2</td>
<td>2.6</td>
<td>7.2</td>
</tr>
<tr>
<td>&gt;=2</td>
<td>1.3</td>
<td>2.0</td>
</tr>
</tbody>
</table>
The impact of changing the traffic safety

If a fixed dough to make pizza
• Option 1: a deep dish pizza
• Option 2: normal one
If we have a fixed budget to increase traffic safety...

• **Option 1: Smaller area and bigger increase of safety**
  • Increase the safety of all road within the red diamond (the figure at bottom-right) with value of $a$, that is within 0.5 miles from the school

• **Option 2: Bigger area and smaller increase of safety**
  • Increase the safety of all road within the blue diamond with value of $a/4$, that is within 1 miles from the school [*: $a/4$ is because the size of road within blue diamond is four times as the size of road within red diamond]*
Result

Increased percentage of children walking to school
Synergistic effects of the WSB and educational campaign

Compare:
• Implementing the WSB only;
• Increasing positive attitudes towards ATS only;
• Combining both interventions.

We identified a synergistic effect of the WSB in combination with interventions such as educational campaigns that enhance attitudes toward ATS.
To extend the model: limitations and challenges

• Human behavior dimension
  • Psychological properties such as habit could be added
  • Variations of behaviors by age, gender, income level, contexts
  • Interactions within family

• Specific context dimension
  • Public transportation or bicycling
  • Traffic around school

• Specific policy dimension
Discussions
Challenges

• Model boundary and model assumptions
• Individual behavior is complicated
• Development is time consuming
• Parameterization and validation can be demanding
• The model is hard to share, and be understood by others
Lessons from modeling research

- Thinking: systematical, critically, and creatively
- The modeling process may be more important than the model itself
- Challenge within team: balance between various opinions and disciplines
- Population-level knowledge and individual-level rule: an easy pitfall
- Evidence from decades ago: we are not smarter than before