High-Fidelity Agent-Based Modeling to Support Prevention Decision-making

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- Vermeer, W., Hjorth, A., Jenness, S. M., Brown, C. H., & Wilensky, U. (2020). Leveraging modularity during replication: Lessons from replicating a complex agent-based model for HIV prevention. *Journal of Artificial Societies and Social Simulation, 23*(4)
- Vermeer, W., Gurkan, C., Hjorth, A., Benbow, N., Kern, D., Brown, C.H., Wilensky, U. Prevention and care pathways to end the HIV epidemic in Chicago: Projections of an Agent-based model for HIV among MSM. (In Preparation)

Outline

- What are Agent-based models, and why are they useful for decision making
- What makes high-fidelity agent-based models different
- Recommendations on ensuring rigor in our use of high-fidelity agent-based models for prevention
  - With illustrations of our own work on HIV prevention and prevention of opioid related death

What is an agent-based model (ABM)?

An ABM is a computational simulation model

which simulates the behaviors of a set of actors called agents

- Often in social sciences these agents will represent individuals, however they can be virtually anything; an atom, a planet, an individual, an organization, or even a nation.

The behaviors modeled describe an agent's internal rationale, its interactions with others, and how it influences and is influenced by its local environment.

What is an agent-based model (ABM)

As such, ABM describes a system using individual level behaviors.

The main difference with other system science simulation models being in ABM systemic dynamics emerge without being pre-specified.

What is more, their agent-level specification makes ABM particularly suitable to address heterogeneity among individuals, and differences in their social contexts.

Value of ABM for prevention: Capturing systemic behaviors

As ABMs are build up from the smallest units (e.g. individual, or agent) up, they naturally allow for inclusion of more complex organization structures to be included into a single model.

As such they are a natural fit to:

- Describe multi-level in a system
- Capture interactions between various systems
- Incorporate complex feedback loops across these levels

Value of ABM for prevention: Scaling intervention capacity

The virtual nature of ABM presents a unique opportunity to perturb systems and explore impacts.

Exploring a perturbation to a system or behaviors ---be it an intervention or a change in the environment--- is quite literally as simple as a click of a button.

This reduced ‘cost’ of intervention allows for explorations, including those with combinations of perturbations, that are simply infeasible in the real world.

What is more, such experiments can be conducted without the risks of doing harm in the real world, making it particularly suitable for exploring the impact of de-implementation

Value of ABM for prevention: Providing timely lessons

While model building is by no means a trivial task, the resources and time required to do so are relatively small compared to traditional efficacy and effectiveness trails.

This makes ABM both a timely and resource efficient way of exploring systemic impact.

Value of ABM for prevention: Predicting future impacts

The computational nature of ABM implies that time is a dimension one can perturb in the model.

Doing so naturally allows one to simulate future dynamics, and changes in such dynamics.

Under the presumed dynamics, an ABM allows one to predict system impacts well into the future.

What is more, it allows one to explore multiple alternative versions of the future

ABMs can support each of the phases in the EPIS framework

In the Exploration phase; ABM can be used to compare relative effectiveness of multiple intervention programs, and any combinations thereof

In the Preparation phase; ABM can support determinations on how to best implement a given program

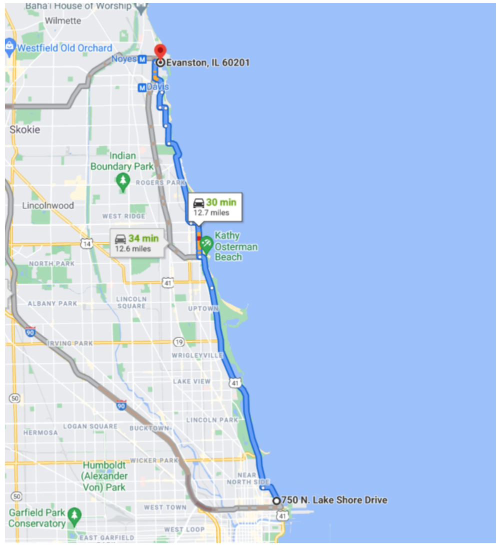
- Show the impact of various target areas or populations
- Show the potential impact of dissemination and distribution strategies

In the Implementation phase; ABM can be used to explore the impacts of removing or reducing barriers from both the inner and outer contexts

In the Sustainment phase; ABM can be used to explore which resources are needed for sustainment, and the potential impacts of resource availability

All models abstract, the extend to which they do in a useful manner will differ

‘All models are wrong, but some models are useful.’



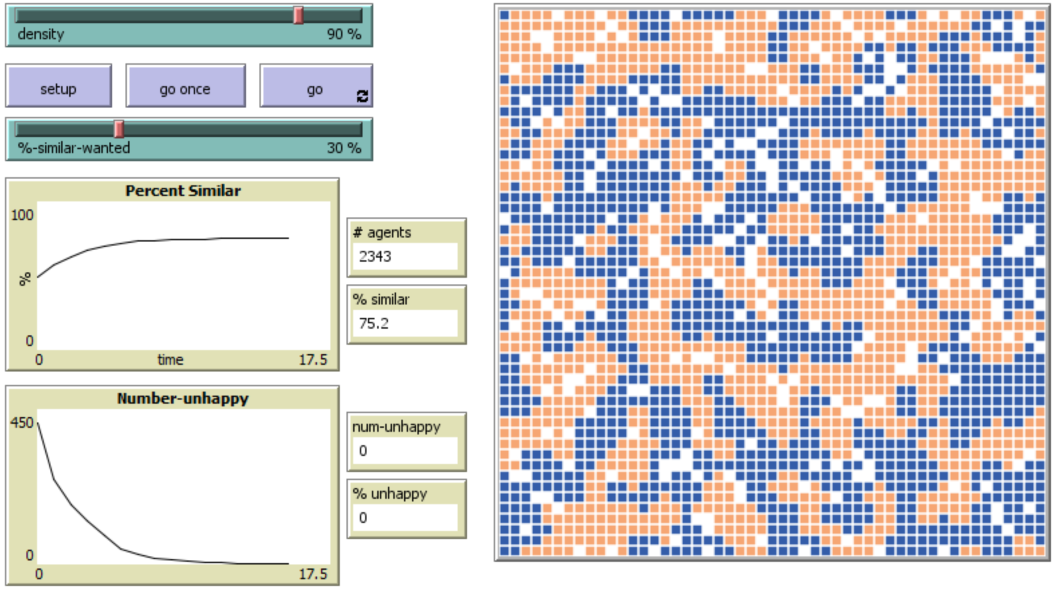
- A model’s functionality is tied to its intended use, so a model’s scope and context matter

Not all ABMs have the same goal: Theory generating models

Theory generating models aim to:

a) Highlight a general relationship between dimensions in a model
   - X can cause Y
   - a small change in X yields a large change in Y (non-linearity)

b) Explain the causes an observed phenomenon
   - X can cause Y
   - X is required for Y
   - There is a tipping point in Y



Not all ABMs have the same goal: Theory generating models

Consequently, theory generating models:

a) Abstract a phenomenon to its core principals
b) Simplify as much as possible
c) Can be highly conceptual
d) Are generally build for addressing a single (predetermined) goal or question

Not all ABMs have the same goal:
High-Fidelity models

High-fidelity models aim to:

a) Realistically capture a phenomenon
b) Embed the model dynamics in an appropriate context
c) Incorporate all dimensions potentially relevant to a phenomenon

Not all ABMs have the same goal: High-Fidelity models

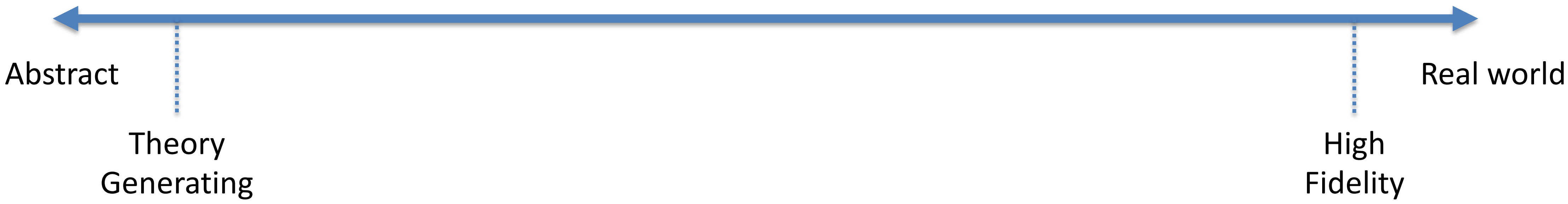
Consequently, High-fidelity models:

a) Have behaviors that are grounded in field data
b) Are generally linking to a specific real-world context
c) Are more complex, in terms of the number of dimensions they include
d) Allow for a wide range of questions to be explored

All ABMs can be placed on spectrum ranging from abstract, to realistic

Theory generating models exist on the abstract end of the spectrum

High-Fidelity models exist on the realistic end of the spectrum



While these types of models are clearly different, the bounds of what constitutes either one of these types is not strictly defined

Model supported decision making for prevention requires High-Fidelity models

For effective preventive decision making one needs models that:

- Capture accurate individual level behaviors
- Incorporate differences across individuals
- Account for local contextual details and dynamics
- Allow differentiating across nuances in implementation strategies and intervention implementations

All supporting the notion that High-Fidelity ABMs are generally desired when using simulation models for supporting preventive decision making

Rigor in High-Fidelity modeling is critical to ensure a successful adoption of this methodology in prevention

- To build on prior modeling knowledge (and stand on shoulders of giants) it is critical this foundation is solid
- To evaluate the quality of modeling outcomes its is critical a structured modeling process is adopted
- To build trust in the capability of ABMs to support decision making among community partners a transparent modeling process is required

Three pillars for rigorous high-fidelity modeling:

- Ensuring the quality of the models created (validation)
- Include community partners in the modeling process (collaboration)
- Creating generalizable knowledge on which to build (replication)

A model for HIV prevention among MSM in Chicago

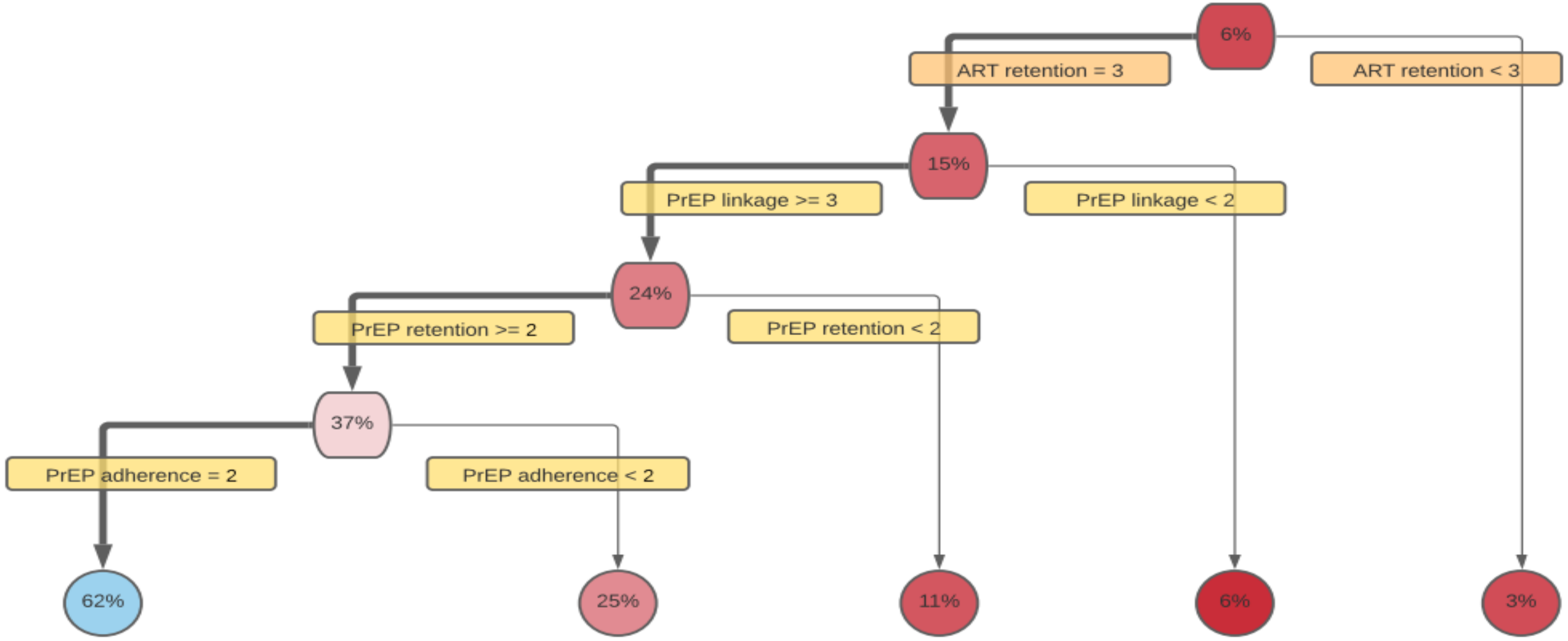
To support local decision making around the best strategies for ending the HIV epidemic (EHE) we build a model in collaboration with the Chicago Department of Public Health (CDPH).

This module consists of six general modules:

1. A **Demographics** module: Describing the population characteristics
2. A **Partnership dynamics** module: Describing the formation and dissolution of the sexual activity networks
3. A **HIV transmission** module: Describing the mechanisms by which sex in serodiscordant pairs can result in transmission of HIV
4. A **Care/treatment** module: Describing the ways by which individuals interact and flow through the treatment and care systems
5. A **Health disparities** module: Describing (some of) the local disparities attributing to HIV risks
6. An **Intervention** module: describing how the model is perturbed during intervention

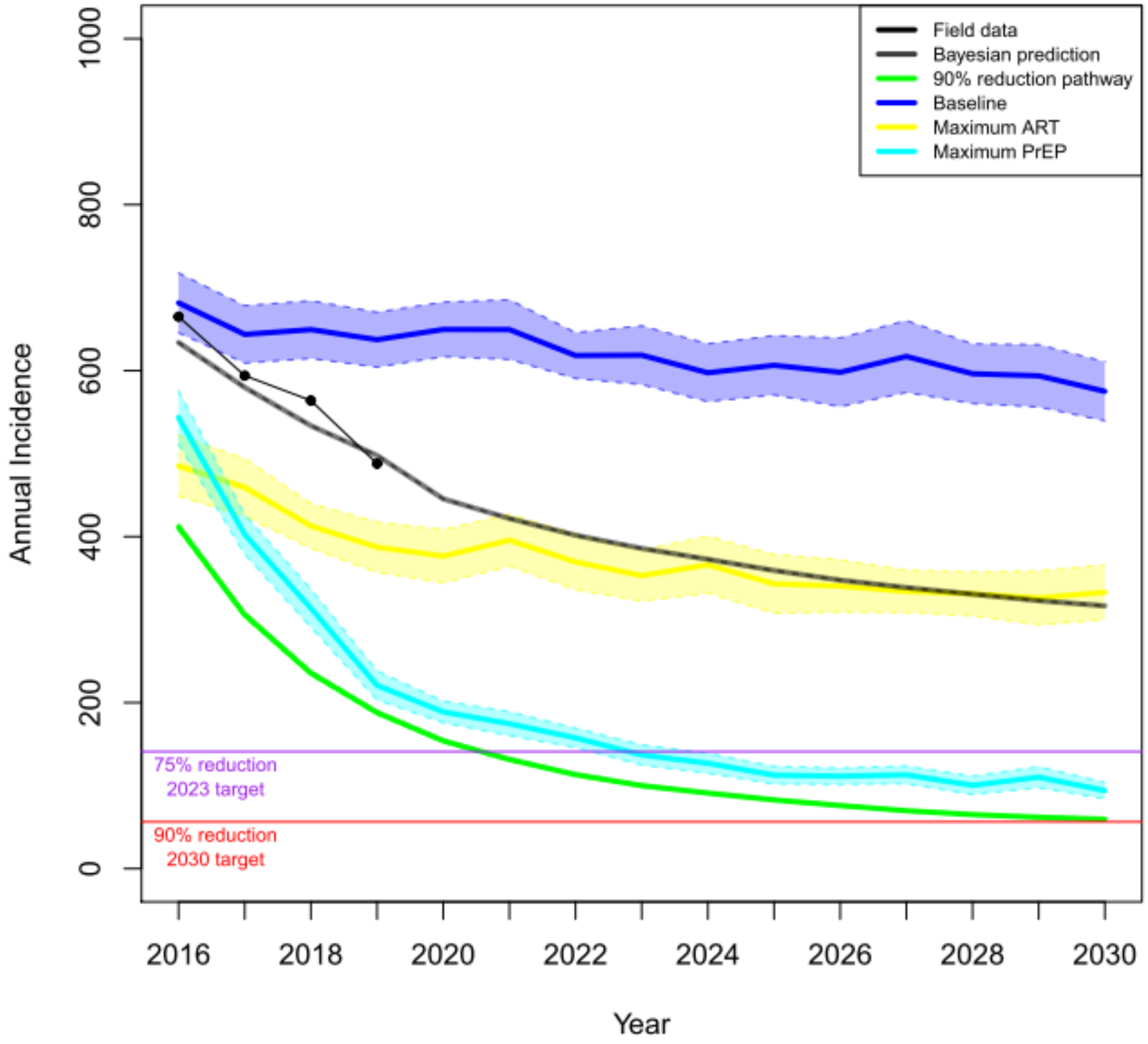
A model for HIV prevention among MSM in Chicago

Our modeling suggests that attaining the goal of 90% reduction in HIV incidence by 2030 requires substantial increases in both PrEP and ART simultaneously.



A model for HIV prevention among MSM in Chicago

And that current efforts are extremely unlikely to get us even close to that goal



Ensuring model validity:
Incorporate data specific to the context studied

Often the nuances in the local context matter, the only way to capture these is to base the model dynamics on local data.

In our HIV model local data is used throughout the model:

The **Demographics** module is based on Chicago census data

The **Partnership dynamics** module is based on Radar data, a Chicago based cohort

The **Care/treatment** module is based on CDPH surveillance data

The **Health disparities** module is based on local HIV surveillance and Hardship data.

The **HIV transmission** module is intentionally not based on local data as transmission mechanics are not influenced by the context in which they occur.

The **Intervention** module has the purpose of perturbing the baseline local rates

Ensuring model validity:
Validate both at the agent- and system-level if possible

ABMs have behaviors at (at least) two levels: the agent-level and the system level.

On both levels model behavior can and should be validated.

First, use field data to build agent-level behaviors that accurately follow these observations

Next, let system-level dynamics emerge and check it against field data to see of these behaviors match

Ensuring model validity: Use model fitting with caution

A common modeling practice is to obscure or 'address' discrepancies in alignment by introducing one or more fitting terms.

Generally, the arguments for including such fitting terms are uncertainties in the input data, incorrect modeling assumptions, or exclusion of important variables.

While exceptions exist the use of such "kluge factors" is highly discouraged, especially in high-fidelity ABMs.

Ensuring model validity:
Report on the process of model validation

Due to their foundation in field data, for high-fidelity ABMs model validation is a natural part of the model building process.

This process is however rarely reported or shared with peers and stakeholders.

We recommend the adoption of **TRA**nsparent and **C**omprehensive **E**cological modeling documentation guidelines (TRACE)* to document and report the modeling process

*Ayllon et al. (2021) Keeping modelling notebooks with TRACE: Good for you and good for environmental research and management support. *Environmental Modelling & Software, 136*

Ensuring model validity:
Report on the process of model validation

TRACE asks modelers to keep a notebook of their model-building efforts and organize it using 8 main elements:

- Problem formulation
- Model description
- Data evaluation
- Conceptual model evaluation
- Implementation verification
- Model output verification
- Model analysis and application
- Model output corroboration

Ensuring model validity:
Report model misalignments and shortcomings

Reporting the validation process using TRACE presents an opportunity to identify misalignments, however current reporting standards incentivize obscuring misalignments rather than foregrounding them.

We recommend devoting a sub-section in the Model Analysis and Model Output Corroboration sections in TRACE to specifically highlighting misalignment, their hypothesized causes, and potential ways they could be improved

Ensuring model validity: Report model outcome variance

Model outcomes are often summarized by considering the mean behavior.

However, we need to be skeptical of mean behavior. Without further exploration there is no ground to assume that this behavior is representative, or even likely to occur, both in the model and as a real-world phenomena.

We need to always explore the distribution of outcomes to properly understand

Ensuring model validity: Report model outcome robustness

Model robustness refers to the extent to which model dynamics and outcomes will change as a result of perturbations in the behaviors or inputs used.

In dealing with imperfect information during model building, one is bound to run into grey areas where an assumption must be made. This is particularly likely in complex High-Fidelity models.

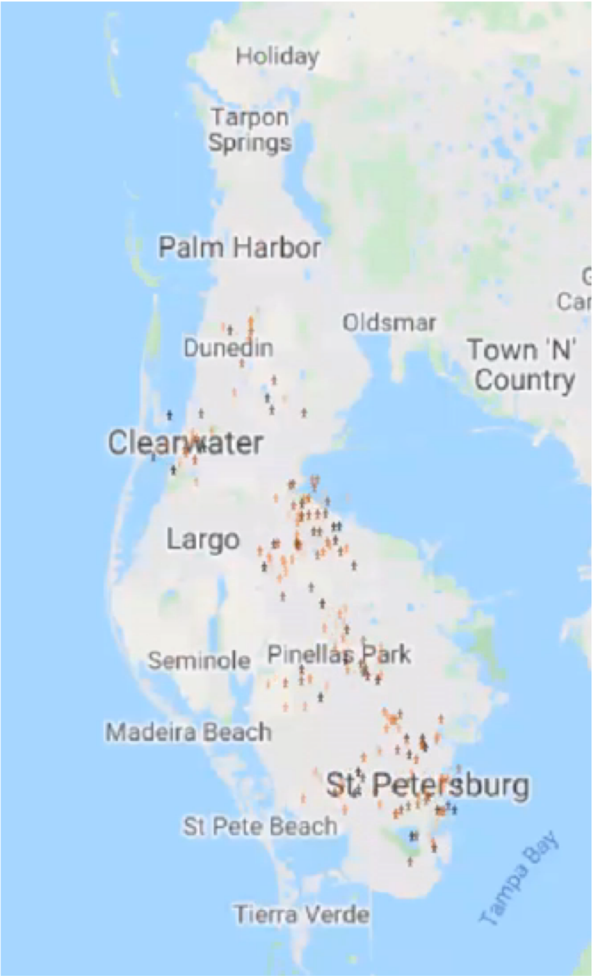
While most assumptions are minor, for those where one is uncertain, one should explore and report the potential impact

A model for preventing Opioid related deaths in Pinellas county, FL

To find actionable strategies to address the rising number of opioid related deaths in PC we partnered with the local opioid task force to build an ABM of local overdose dynamics

This model consists of eight general modules:

1. **Demographics module:** determining the characteristics of the people
2. **Social interaction module:** determining interaction with among people and with their environment
3. **Usage module:** determining the consumption of drugs (use preferences)
4. **OD module**: determining the risk of OD during consumption (mortality causes)
5. **Rescue/Narcan module:** determining the chance of reversal using Narcan
6. **Care/treatment module:** determining the opioid related care provided
7. **Jail module:** determining individual's interactions with the jail system
8. **Intervention module:** specifying interventions for which to explore the impact



Include stakeholders:
Answer locally relevant questions

From its initiation onward this project has been based on inputs from the Taskforce members. Specifically, the taskforce has :

- Identified the key dimensions in the model
- Referred us to critical sources of local data
- Prioritized the strategies to pursue in our explorations with the model

Our initial focus on exploring the impact of Narcan provision and distribution is a direct result of the priorities identified by interviewing these community partners.

Include stakeholders: Use local expertise to validate model behaviors

As soon as data became available for analysis, we fed back these results to the taskforce.

We used their local knowledge of the system to verified trends found and validate that what we use as input for the model makes sense.

The expertise of community partners is yet another way in which individual level behaviors can be validated and context to the local data can be created.

Include stakeholders: Treat model building as a collaborative process

Our model building process is set up in such a way that input from the taskforce is incorporated during each step we take.

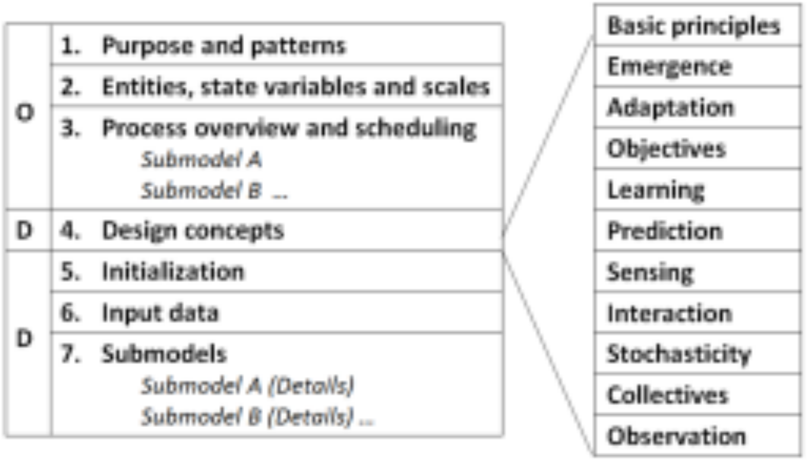
What is more, the modeling we do is in service of the community, our partners are in the lead, and guide us to where they need insights. We support their requests as best we can.

This approach to model building not only gives the community partners ownership over the artifact created, it also increases their understanding of the model, its affordance, and its limitations.

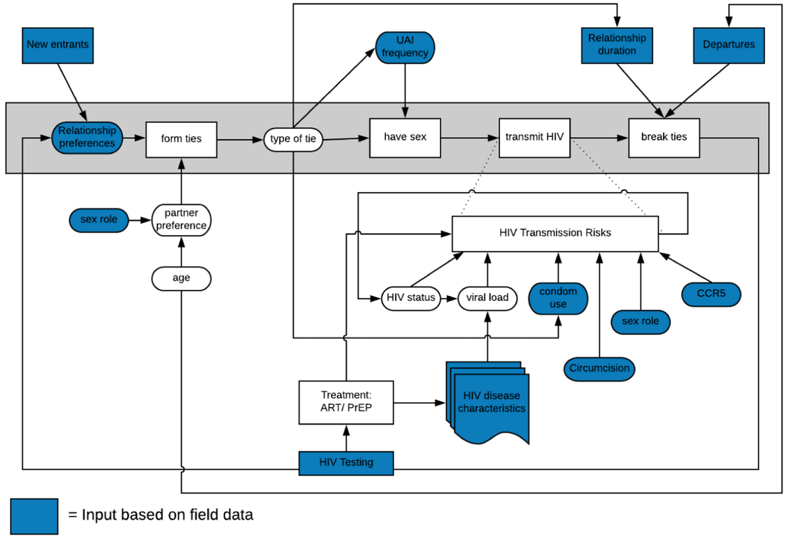
This is the only way to truly work towards sustained use of model supported decision making by community partners.

Facilitate replication: Standardize model documentation

To reduce the burden of understanding ABMs we recommend adopting standards in reporting on model behaviors, prime example is ODD*



However as High-fidelity models are complex, their structure is not easily deduced even from ODD, as such we recommend Including a model flow diagram in the model description



*Grimm et al. (2020) The ODD Protocol for Describing Agent-Based and Other Simulation Models: A Second Update to Improve Clarity, Replication, and Structural Realism. *JASSS, 23(7)*

Facilitate replication: Leverage modularity of models

To increase the ease by which models and modeling knowledge can reused and build upon one should build model in a modular way.

Each module has fixed shape of its inputs and outputs, but functions relatively independent of the remainder of the model code.

This modular structure allows one to update or replace sections of the model without the need to completely rebuild a model, allowing both for incremental improvements, and increased potential of reusing existing work

Facilitate replication:
Embrace a culture of replication

While incentives in publishing culture might not be in place to facilitate replication, one should embrace replication as a critical goal in modeling practice

- Think of your models and documentation as a steppingstone for ongoing knowledge creation
- Publish and report on models in such a way that others can leverage what you have done
- Reporting using structured standards like ODD and TRACE

Facilitate replication: Share all modeling artifacts

- Share the code of all models you publish, as this is the only way to reuse modules of interest
- Share input data (whenever possible)
- Share validity and module testing scripts
- Be willing to answer additional questions and inquires relating to the model and the modeling process

Recommendations in overview:
Vermeer et al. (2021) in press, Prevention Science

	Subdomains	Action steps
Ensuring model validity	a. Validate both on the agent- and system-level	- Build models using agent behaviors based on individuals' data, and validate emerging system dynamics
	b. Increase model fidelity by integrating local data	- Build models using data that is specific to the context that is studied
	c. Report the validation process	- Adopt TRACE standard to report the modeling and validation process
	d. Report misalignments and model shortcomings	Include a specific on misalignments, in the Model Output Corroboration section of TRACE
	e. Use model fitting with caution	- Caution against including fitting terms without a good reason
	f. Present outcome variance	- Always present a distribution of results and discuss the variability of model outcomes
	g. Evaluate model robustness	- Always include a sensitivity analysis as part of disseminated modeling results
Facilitating replication	a. Support a culture of replication	Require ODD and TRACE documents as part of the publication process
	b. Leverage modularity	- Reduce complexity of replication by replicating one module at a time
	c. Standardize model documentation	- Adopt ODD in documentation - Include a modular flow diagram in the Overview section of the ODD
	d. Make model code publicly available e. Share input data when possible	- Share as many artifacts of the modeling process as possible, including TRACE, ODD, and modeling code, and input data - Be willing to answer additional validation and replication questions
Acceptance, adoption, ownership, and use by stakeholders	a. Include community partners in the model building process	- Partner with community stakeholders as early as possible in the modeling process - Focus on answering locally relevant questions - Leverage local stakeholder knowledge for model validation

In summary

There is enormous potential for ABM to support prevention and implementation science.

To achieve this potential, we need a rigorous High-Fidelity modeling process, which is build on the following principals:

- Building high-quality, validated models (validation)
- Inclusion of community partners in the modeling process (collaboration)
- A focus on creating generalizable knowledge on which to build (facilitate replication)