A Next-Generation Analytical Approach to Policy Design: Complete Agent-Based Modeling (c-ABM)

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Policy Design for Critical Societal Issues

General Goals: Understand how existing real-world policies
— are currently performing;
— could be designed to perform better.

Any modeling method used to support these general goals must simplify reality; but should nevertheless be flexible as well as logically rigorous, permitting:

1) Careful tailoring of model simplifications to purposes at hand
2) Dynamic events to be modeled as open-ended cause-effect processes
3) Careful matching of modeled agents to empirical referents

Example: “Human” agents should be permitted “to breathe”.

• Standard economic modeling methods: do not permit 1), 2), and 3).
• Complete Agent-Based Modeling (c-ABM) does permit 1), 2), and 3).
Complete Agent-Based Modeling (c-ABM)
http://www2.econ.iastate.edu/tesfatsi/ace.htm

- **Rough Description:** Modeling of real-world dynamic systems as open-ended systems of interacting agents
- **Axiomatic Characterization:** Seven specific modeling principles

**Key features and capabilities:**

- Enables “historical” study of real-world dynamic systems as unfolding sequences of events.
- Events are fully driven by agent interactions, starting from initially specified agent states (i.e., data, attributes, and/or methods).
- Agents can be broadly specified to represent physical, biological, social, and/or institutional entities.
- Role of the modeler is restricted to the specification of initial agent states, and to non-perturbational observation, recording, and analysis of model outcomes. (*culture-dish modeling*)
c-ABM Modeling Principles (MP1) – (MP7)

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(MP1) Agent Definition: An *agent* is a software entity within a computationally constructed world that can affect world outcomes through expressed actions.

(MP2) Agent Scope: Agents can represent a broad range of entities, e.g., individual life-forms, social groupings, institutions, and/or physical phenomena.

(MP3) Agent Local Constructivity: An intended action of an agent at any given instant is determined by the agent’s *state (data, attributes, and/or methods)* at this instant.
(MP4) **Agent Autonomy:** All agent interactions (expressed agent actions) at any given instant are determined by the ensemble of agent states at this instant.

(MP5) **System Constructivity:** The state of the world at any given instant is determined by the ensemble of agent states at this instant.

(MP6) **System Historicity:** Given an initial ensemble of agent states, any subsequent world event (change in agent states) is induced by prior and/or concurrent agent interactions.

(MP7) **Modeler as Culture-Dish Experimenter:** The role of the modeler is limited to the configuration and setting of initial agent states, and to the non-perturbational observation, analysis, and reporting of world outcomes.
c-ABM Permits Comprehensive Bottom-to-Top Empirical Validation *Tailored to Policy Purpose*

[http://www2.econ.iastate.edu/tesfatsi/EmpValid.htm](http://www2.econ.iastate.edu/tesfatsi/EmpValid.htm)

**EV1. Input Validation**

Are the exogenous inputs for a model *empirically meaningful and appropriate for purpose at hand?*

**Exogenous Input Examples:** Initial state conditions, functional forms, shock realizations, data-based parameter estimates, &/or parameter values imported from other studies

**EV2. Process Validation**

— Do modeled physical, biological, institutional, & social processes *reflect real-world aspects important for purpose at hand?*

— Are process specifications *consistent with essential scaffolding constraints*, such as physical laws, stock-flow relationships, and accounting identities?

**EV3. Descriptive Output Validation:**

How well are model-generated outputs able to *capture salient features of the sample data* that was used for model identification? (*in-sample fitting*)

**EV4. Predictive Output Validation:**

How well are model-generated outputs able to *forecast distributions or distribution moments* either for sample data withheld from model identification, or for later acquired data? (*out-of-sample forecasting*)
c-ABM Permits Policy Design for Critical Societal Issues that Cross Traditional Disciplinary Boundaries


Goal: Transform global energy sector into a net-zero CO2 emissions sector by 2050

Possible Approach: Use c-ABM co-simulation platforms for development and testing of proposed new Electric Power Market Designs

Example: ITD TES Platform V2 (Open Source, Java/Python/C++, GitHub Repository)

— Developed by econ/engineering team at Iowa State U & Pacific Northwest National Lab (PNNL)

— Permits formulation & performance testing of Transactive Energy System (TES) designs as possible pathways to Net-Zero 2050 for electric power systems consisting of Integrated Transmission and Distribution (ITD) systems.

— Funded by: U.S. Department of Energy (DOE), PNNL, National Science Foundation (NSF), Sandia National Lab (SNL), Los Alamos National Lab (LANL), Power Systems Engineering Research Center (PSERC, Cornell U), and the Electric Power Research Center (EPRC, ISU)

— https://www2.econ.iastate.edu/tesfatsi/ITDProjectHome.htm
ITD TES Platform V2: Illustrative Implementation

An Integrated Transmission and Distribution (ITD) system for which:

(i) A 123-node distribution network is populated by 927 households;
(ii) Each household has a Heating, Ventilation, & Air-Conditioning (HVAC) system;
(iii) Each HVAC system is smartly controlled (i.e., responsive to price signals)
(iv) The 123-node distribution network is linked to an 8-node transmission network

\[ \text{IDSIO} = \text{Independent Distribution System Operator} \ (\text{manages distribution system}) \]
\[ \text{LSE} = \text{Load-Serving Entity} \ (\text{submits retail customer power demands into wholesale power market}) \]
**Design Readiness Levels (DRLs)**

**DRL-1:** Conceptual design idea

**DRL-2:** Analytic formulation

**DRL-3:** Low-fidelity small-scale modeling

**DRL-4:** Moderate-fidelity moderate-scale modeling

**DRL-5:** High-fidelity moderate-scale modeling

**DRL-6:** Pilot study (reflects *expected* field conditions *apart from scale*)

**DRL-7:** Prototype large-scale modeling (reflects *expected* field conditions)

**DRL-8:** Field study

**DRL-9:** Real-world implementation

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**c-ABM Helps Bridge “Valley of Death” for Policy Design Studies**

Basic research carried out at universities...

Valley of Death

Government, business, regulatory agencies ...
c-ABM Supports **Iterative Participatory Modeling (IPM)**

**Example:** IPM for Complex Policy Design Problems

— Researchers & stakeholders repeatedly cycle through Design Readiness Levels (DRLs) 1-9 in an ongoing open-ended learning process.

— In each cycle, use of a c-ABM platform can help ensure progression thru **Valley of Death (DRLs 4-6).**

**Goal:** Continual policy improvement rather than the attempted delivery of definitive policy solutions.
c-ABM and 100% Human-Subject Experiments are Boundary Points for Broad Spectrum of Experimental Methods Suitable for Policy Design
Background Materials (With Links)

- Agent-Based Computational Economics: A Complete Agent-Based Modeling (c-ABM) Approach
  https://www2.econ.iastate.edu/tesfatsi/ace.htm

- On-Line Guide for Newcomers to Agent-Based Modeling in the Social Sciences
  https://www2.econ.iastate.edu/tesfatsi/abmread.htm

- Empirical Validation of c-ABM Models
  https://www2.econ.iastate.edu/tesfatsi/EmpValid.htm

- Integrated Transmission and Distribution (ITD) Project: ISU Homepage
  https://www2.econ.iastate.edu/tesfatsi/ITDProjectHome.htm

  https://www2.econ.iastate.edu/tesfatsi/SCBookSlideSetOverview.pdf


  https://lib.dr.iastate.edu/econ_workingpapers/23