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)**.

*C*omplete *A*gent-*B*ased *M*odeling (*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)

http://www2.econ.iastate.edu/tesfatsi/ace.htm

(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.

c-ABM Modeling Principles … Continued

(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

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*

Illustration: **Net-Zero 2050** (International Energy Agency Report, Oct 2021)

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 & **P**acific **N**orthwest **N**ational **L**ab (**PNNL**)
- Permits formulation & performance testing of **T**ransactive **E**nergy **S**ystem (**TES**) designs as possible pathways to Net-Zero 2050 for electric power systems consisting of **I**ntegrated **T**ransmission and **D**istribution (**ITD**) systems.
- **Funded by:** U.S. **D**epartment **o**f **E**nergy (**DOE**), PNNL, **N**ational **S**cience **F**oundation (**NSF**), **S**andia **N**ational **L**ab (**SNL**), **L**os **A**lamos **N**ational **L**ab (**LANL**), **P**ower **S**ystems **E**ngineering **R**esearch **C**enter (**PSERC**, Cornell U), and the **E**lectric **P**ower **R**esearch **C**enter (**EPRC**, ISU)
- **https://www2.econ.iastate.edu/tesfatsi/ITDProjectHome.htm**

ITD TES Platform V2: Illustrative Implementation

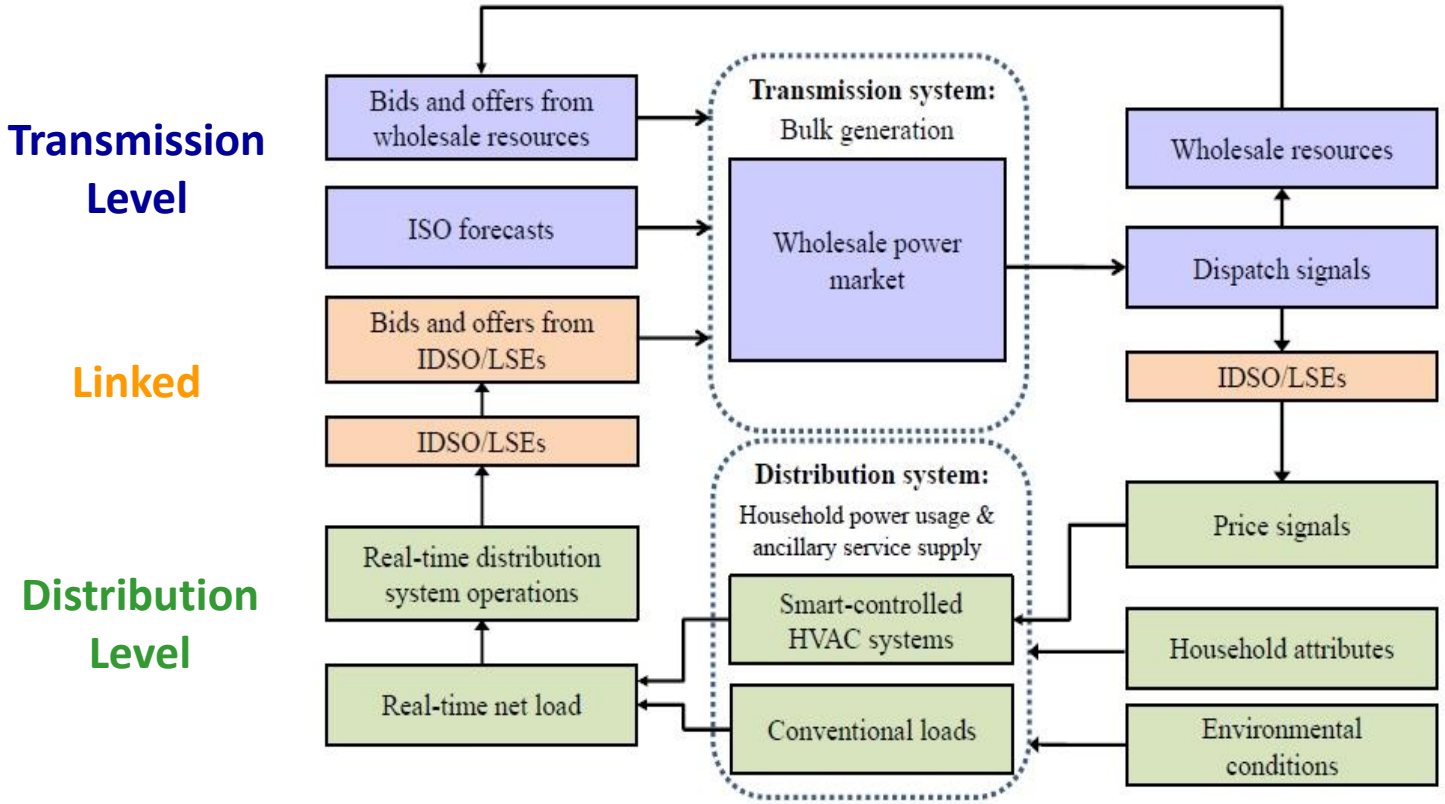
An *I*ntegrated *T*ransmission and *D*istribution (*ITD*) system for which:

(i) A 123-node distribution network is populated by 927 households;

(ii) Each household has a *H*eating, *V*entilation, & *A*ir-*C*onditioning (*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



IDSO = *I*ndependent *D*istribution *S*ystem *O*perator (manages distribution system)

LSE = *L*oad-*S*erving *E*ntity (submits retail customer power demands into wholesale power market)

c-ABM Helps Bridge "Valley of Death" for Policy Design Studies

Design Readiness Levels (DRLs)

DRL-1: Conceptual design idea

DRL-2: Analytic formulation

DRL-3: Low-fidelity small-scale modeling

Basic research carried out at universities...

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***)

Valley of Death

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

DRL-8: Field study

DRL-9: Real-world implementation

Government, business, regulatory agencies …

c-ABM Supports *I*terative *P*articipatory *M*odeling (*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**).

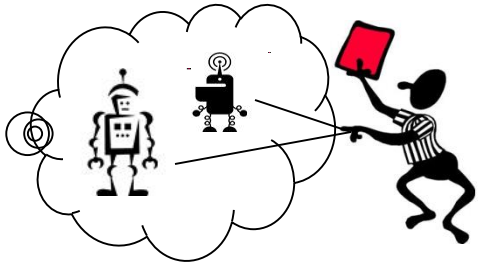
Goal: Continual policy improvement rather than the attempted delivery of definitive policy solutions.

c-ABM and 100% Human-Subject Experiments are Boundary Points for *Broad Spectrum of Experimental Methods Suitable for Policy Design*

100% human

Humans with computer access

Human-controlled computer avatars

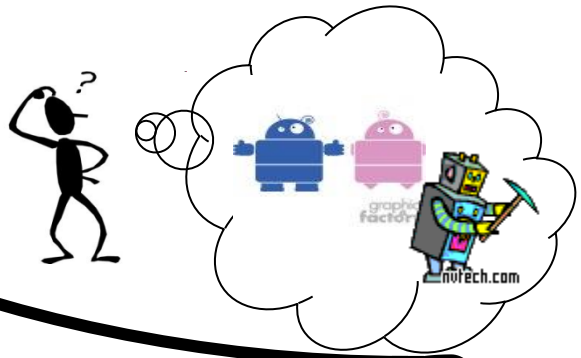


Tethered

Mix of humans and computer agents

Not Tethered

Human-calibrated computer agents



Computer agents with real-world data streaming

100% computer agents evolved from initial conditions **(c-ABM)**

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

- Leigh Tesfatsion (2021). ***A New Swing-Contract Design for Wholesale Power Markets***, 20 Chps., 288pp., John Wiley & Sons (IEEE Press Series on Power Engineering), Hoboken, New Jersey, USA.
  https://www2.econ.iastate.edu/tesfatsi/SCBookSlideSetOverview.pdf

- Leigh Tesfatsion (2018) , "**Electric Power Markets in Transition: Agent-Based Modeling Tools for Transactive Energy Support**" **(Preprint)**, Ch. 13 (pp. 715-766) in C. Hommes & B. LeBaron (Eds.), *Handbook of Computational Economics 4: Heterogeneous Agent Models*, Handbooks in Economics Series, North Holland (Elsevier), Amsterdam, the Netherlands.

- Leigh Tesfatsion (2017), "**Modeling Economic Systems as Locally-Constructive Sequential Games,**" *Journal of Economic Methodology*, Vol. 24, Issue 4, pp 384-409
  https://lib.dr.iastate.edu/econ_workingpapers/23