Wholesale Power Market Design

An Agent-Based Computational Economics Approach

Presenters:

Leigh Tesfatsion

and

Deddy Koesrindartoto

Department of Economics

Iowa State University

Ames, Iowa 50011-1070

Outline

- What is Agent-Based Computational Economics (ACE)?
- ACE and Electricity Market Design
- Illustrative Application (Electricity Double Auction)
- A More Substantial Application (Testing the reliability of FERC's 2003 Wholesale Power Market Platform design)

What is ACE?

- Computational study of economies modeled as evolving systems of autonomous interacting agents with learning capabilities

- Specialization to economics of the basic complex adaptive systems paradigm

Culture Dish Analogy

- Virtual economic world with both passive and active agents
- Modeler sets initial conditions of the world
- The world then evolves over time without further outside intervention
- Driven solely by agent-agent interactions

Current ACE Research Areas

(http://www.econ.iastate.edu/tesfatsi/aapplic.htm)

- Embodied cognition
- Network formation
- Evolution of norms
- Specific market case studies
- Industrial organization
- Market Design
- Automated markets and software agents
- Development of computational laboratories
- Parallel experiments with real and computational agents
- Others…

Economic Research on Electricity Market Design
(www.econ.iastate.edu/tesfatsi/epres.htm)

- ***Analytical/Empirical:***
  - Berkeley (Borenstein, Bushnell, Oren,...); Cambridge (Green, Newbery,...); EPRI (Chao, Peck,...); Harvard (Hogan,...); MIT (Joskow, Tirole,...); U of Oslo (Halseth, von der Fehr,...); Stanford (Wilson, Wolak,...); …
- ***Human-Subject Experiments:***
  - Cornell (Mount,...); George Mason U (Rassenti, Smith, Wilson,...); ...

Potential Contributions of ACE Approach

- Key market participants (system operator, generators, buyers...) modeled as **autonomous interacting agents**
- **Agent learning** can be calibrated to data (empirical, human-subject experimental)
- Behaviors and interaction networks **evolve over time**
- Easier to include and test **detailed structural market features** for individual and/or joint effects

• *ACE Electricity Research:* *(www.econ.iastate.edu/tesfatsi/aelect.htm)*

- Argonne National Lab (Macal, North,...)
- CSIRO-Australia (Batten,...)
- Helsinki Univ. (Hamalainen,...)
- Iowa State University (Koesrindartoto, Sheble, Tesfatsion,...)
- London Business School (Bunn, Day,...)
- Los Alamos National Lab (Barrett, Marathe,...)
- Pacific Northwest National Lab (Roop,...)

- Others (see website above)

Key Issues for Wholesale Power Markets

- ***Short-Run:*** Efficient production of electricity from ***existing*** generation capacity
- ***Short-Run:*** Efficient transmission of electricity to ***existing*** load-serving entities over ***existing*** transmission lines
- ***Longer-Run:*** Efficient planning and investment for ***new*** generation and ***new*** transmission capacity

Illustrative ACE Study of a Wholesale Power Market

"Market Power and Efficiency in a Computational Electricity Market with Discriminatory Double-Auction Pricing"

J. Nicolaisen, V. Petrov, and L. Tesfatsion,
IEEE Transactions on Evolutionary Computation
5(5), October 2001, 504-523

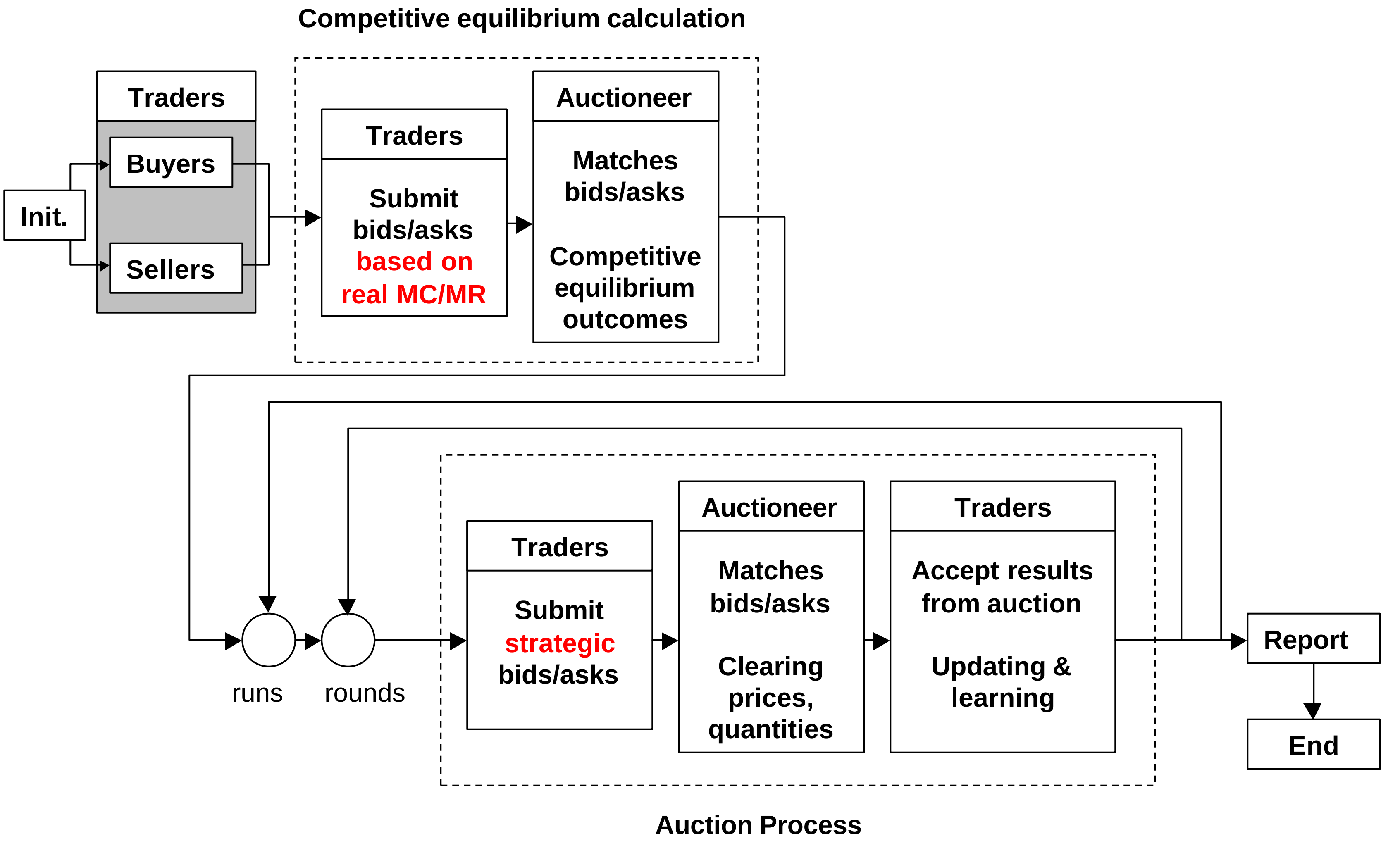
ACE Wholesale Power Market: Basic Structure

- N Generators and M Load-Serving Entities (LSE's)
- Repeated participation in a wholesale power market operated by an Independent System Operator (ISO)
- Market run as a discriminatory double auction
- Fully connected transmission grid (ATC constraints non-binding in this study)

Wholesale Power Market: Logical Flow

- Construct and initialize the Independent System Operator (ISO), the Traders (Generators and LSEs), and the Market
- Compute competitive equilibrium benchmark
- Enter the auction loop
- ISO runs auction for RMax rounds (trader bids/asks ➡ price and quantity outcomes)
- Compare results against competitive equilibrium benchmark

Flow Diagram



Key Issues Addressed

- Sensitivity of market performance to changes in market structure when wholesale traders evolve their bid/ask pricing strategies over time.
- Is market structure strongly predictive of market performance despite learning effects?

Two Structural Treatment Factors

Let "Sellers" = Generators and
"Buyers" = Load-Serving Entities

- **RCON = Relative Concentration**
  - Ratio NS/NB of Number of Sellers to Number of Buyers
- **RCAP = Relative Capacity**
  - Ratio DCAP/SCAP of total buyer demand capacity to total seller supply capacity

Experimental Design

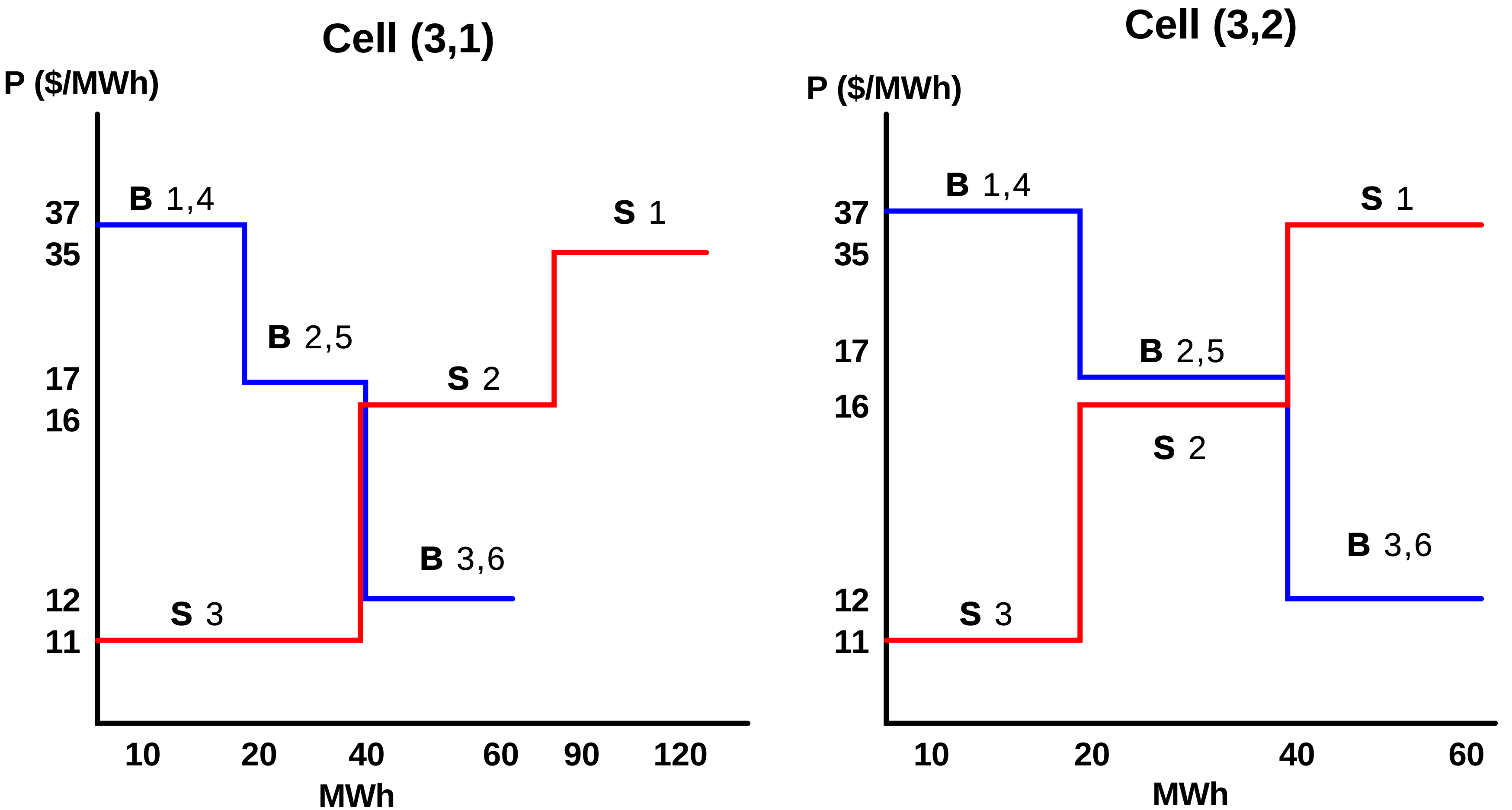
- **Two Structural Treatment Factors:**
  RCAP, RCON

- **Three Tested Treatment Levels:**
  1/2, 1, 2
- **Runs per Treatment:**
  From 1000 to 10,000
- **Data Collected Per Run:**
  Market efficiency; Seller market advantage; Buyer market advantage (aggregate and individual levels)

Structural Treatment Factor Values

		RCAP		
		1 / 2	1	2
RCON	2	Ns = 6 Nb = 3 Cs = 10 Cb = 10	Ns = 6 Nb = 3 Cs = 10 Cb = 20	Ns = 6 Nb = 3 Cs = 10 Cb = 40
	1	Ns = 3 Nb = 3 Cs = 20 Cb = 10	Ns = 3 Nb = 3 Cs = 10 Cb = 10	Ns = 3 Nb = 3 Cs = 10 Cb = 20
	1 / 2	Ns = 3 Nb = 6 Cs = 40 Cb = 10	Ns = 6 Nb = 3 Cs = 20 Cb = 10	Ns = 3 Nb = 6 Cs = 10 Cb = 10

Aggregate Demand and Supply



Trader Learning

- Each trader uses ***individual reinforcement learning*** to determine their ask or bid price in each market period

- The entire RCON/RCAP experimental design was implemented three times under ***three different specifications*** for the reinforcement learning algorithm parameters

Trader Learning… Continued

- **Results compared against an earlier electricity study** by the same authors using the same double-auction electricity market structure
- **Difference**: Sellers in *earlier* study used **social mimicry learning** (population-level genetic algorithm), and similarly for buyers, despite structural heterogeneity -- not a smart thing to do!

Market Efficiency

- **ActualProfits** = *Actual* total profits earned by sellers and buyers
- **MaxProfits** = *Maximum possible* total profits that sellers and buyers *could* earn (i.e., total trader profits in competitive equilibrium)
- **Market Efficiency =** *ActualProfits as a percentage of MaxProfits*

Efficiency Findings

- ***HIGH*** market efficiency obtained when the traders use individual reinforcement learning

- ***LOW*** market efficiency obtained when the traders use not-so-smart social mimicry learning

- ***CONCLUSION***:

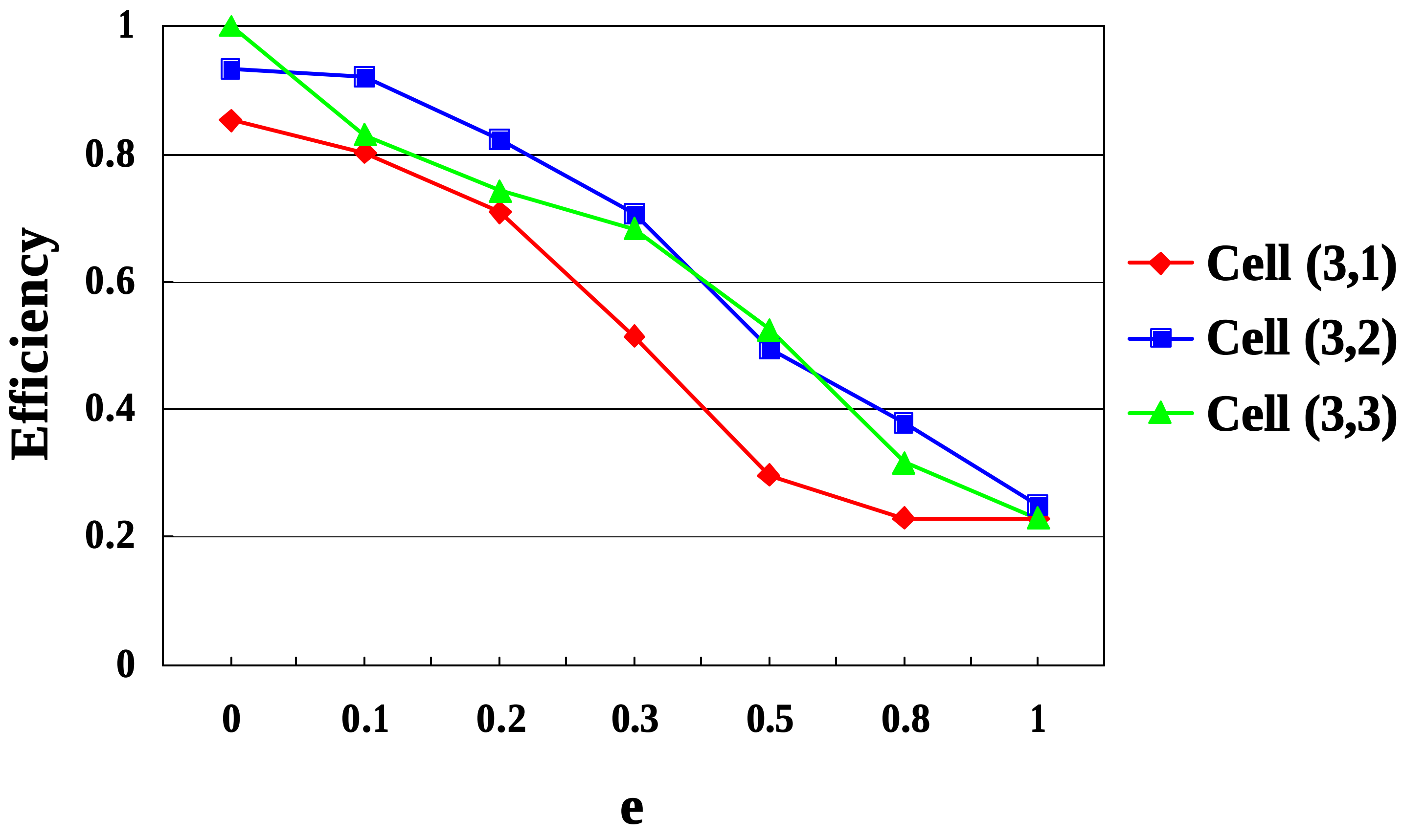
Efficiency of double-auction electricity market ***not*** robust against active exercise of bad judgement (e.g., inappropriate social mimicry)

Additional Findings

(Deddy Koesrindartoto, 2001)

- Even with reinforcement learning (RL), market efficiency can be low for certain parameter values
- ***Example:*** **Roth-Erev RL Algorithm (1998)**
- Experimentation parameter ***e*** (controls how reward from a chosen strategy affects probability of choosing other strategies).
- For some settings of ***e***, market efficiency can be as low as 20 percent

Efficiency vs Experimentation Parameter *e*



Market Advantage

- **Market Advantage:** the ability of traders to secure higher net profits for themselves than they would obtain under competitive market conditions
- **Market Power:** "the ability to profitably alter prices away from competitive levels" (Stoft, *Power System Economics*, 2002, p. 318)
- Market advantage is a **necessary** condition for the exercise of market power.

Structural vs. Strategic Market Advantage

- **Structural Market Advantage:** The market advantage conferred on a trader *by market protocols alone*, assuming all traders bid/ask their true reservation prices (no strategic bid/ask pricing behavior)

- **Strategic Market Advantage:** Any *additional* market advantage that can be secured by a trader *through strategic bid/ask pricing behavior*

Market Advantage: Aggregate Findings

- ***For given RCON***, changes in the aggregate measure RCAP do ***not*** exhibit any meaningful correlation with aggregate seller and buyer market advantage outcomes

- ***For given RCAP***, changes in the aggregate measure RCON have ***only small unsystematic effects*** on aggregate seller and buyer market advantage outcomes.

Market Advantage: Micro Findings

- ***Relative*** market advantage of sellers and buyers can be reliably predicted from the ***market microstructure***.
- Sellers and buyers are ***not*** able to secure increases in ***relative*** market advantage ***through strategic pricing***.
- Actual Market Advantage = Structural Market Advantage
- **Conjecture**: Lack of *strategic* market advantage for traders is due to symmetry of double auction electricity market

Summary of Findings for NPT (IEEE-TEC 2001)

- ***High*** market efficiency is obtained when traders use individual reinforcement learning but ***not*** when they use social mimicry learning.
- The ***microstructure*** of the double auction electricity market is strongly predictive for the ***relative*** market advantage of traders.
- Traders are ***not*** able to increase their ***relative*** market advantage through strategic pricing (importance of demand-side bidding as countervailing power to supply-side offers)

A More Substantial Application

"Testing the reliability of the Wholesale Power Market Platform Proposed by the Federal Energy Regulatory Commission (FERC)"

Joint research by

Deddy Koesrindartoto

and

Leigh Tesfatsion

in association with

Los Alamos National Lab

Work in Progress

Wholesale Power Market Platform - WPMP (FERC, White Paper, 4/03)

WPMP Objectives

- Customer-based competitive wholesale power markets providing reliable service
- Fair and open access to the transmission grid at reasonable prices
- Good price signals to encourage appropriate investment in new generation and new transmission
- Market power mitigation

Key WPMP Features

- Independent operation of the transmission system by RTO/ISO
- Day-ahead electricity market (financial)
- Real-time electricity market to supplement longer-term contracts
- Ancillary services to ensure resource adequacy (e.g., operating reserves,...)
- Congestion management, preferably through Locational Marginal Pricing (LMP) and financial transmission rights
- Market monitoring and market power mitigation

FERC’s Basic WPM Proposal Adopted?

- **Mid-Atlantic states** (PJM) implement similar plan (1998)
- **New York** (NY-ISO) implements similar plan (1999)
- **New England** (NE-ISO) implements similar plan (2003)
- **California** (CAISO) files to adopt similar plan (2003)
- **Midwest** (MISO) **files to adopt** similar plan (7/2003) and **withdraws** filing (10/2003)
- **Opposition** from states in Southeast and Northwest

Our ACE WPM Model

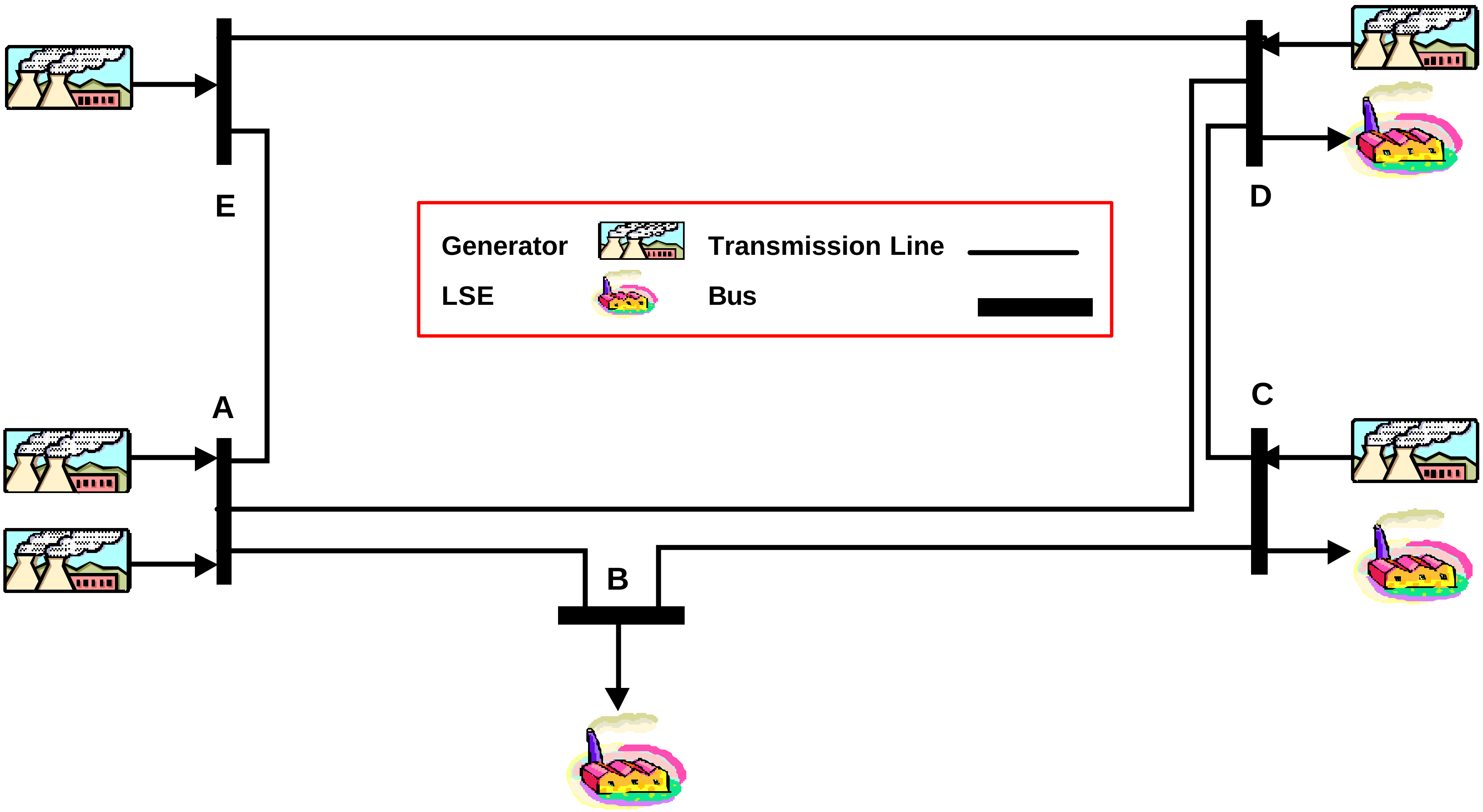
- Based on **Standard Market Design (SMD)** implemented by New England (ISO-NE) on March 1, 2003

- **SMD meets basic WPMP structural requirements:**
  - Independent System Operator (ISO)
  - Day-ahead and real-time electricity markets
  - Congestion managed via Locational Marginal Pricing
  - Financial transmission rights
  - Reserve and capacity markets as well as enhanced demand response (in planning stage)

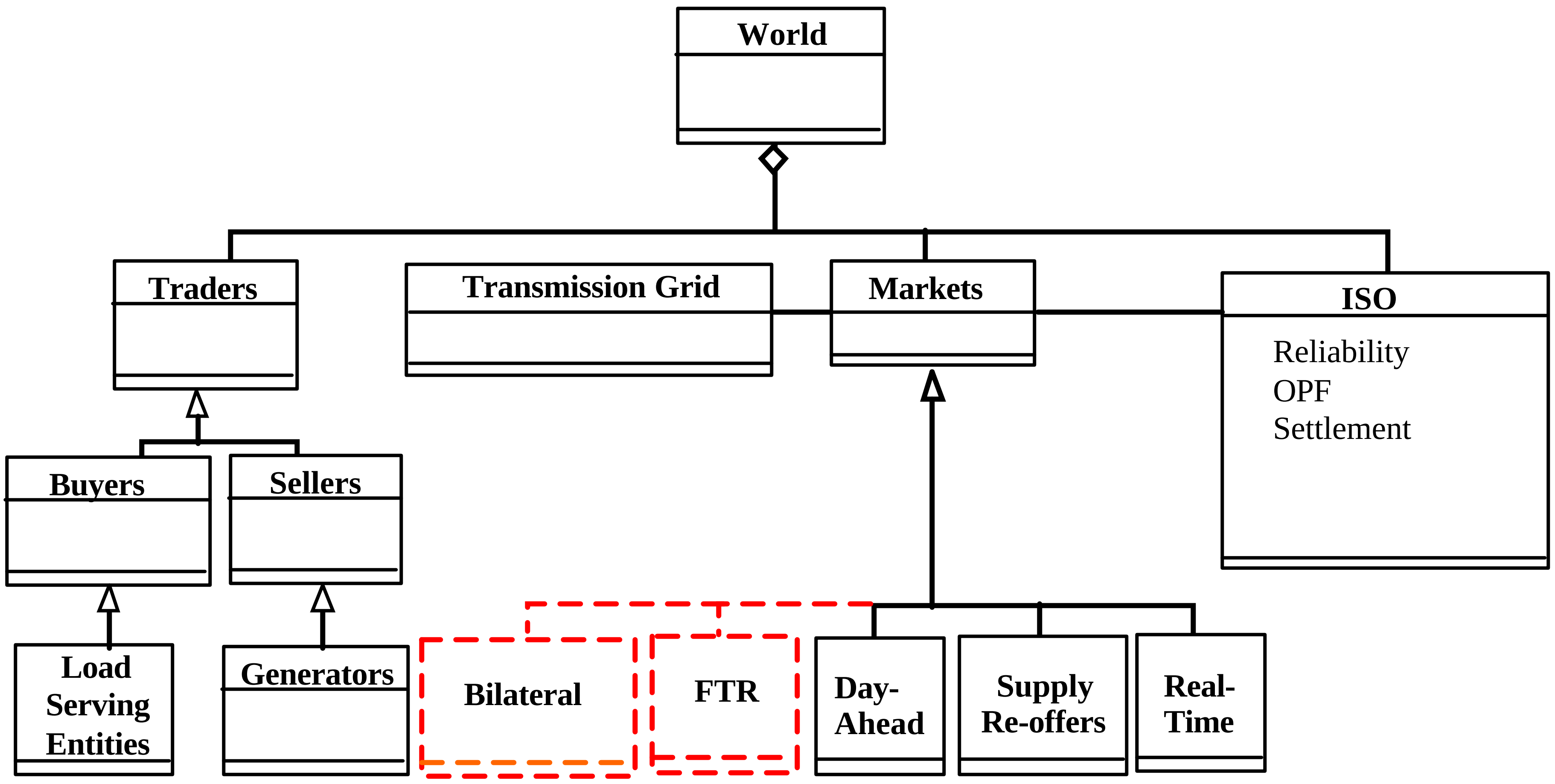
Our ACE WPM Model...

- **Initial Core Model**
  - Independent System Operator (ISO)
  - Day-ahead electricity market
  - Real-time electricity market
  - Congestion managed via LMP
  - AC transmission grid
  - OPF/reliability/settlement handled by ISO
  - 5-bus demo model
- **Planned Model Extensions**
  - Auction market for financial transmission rights (FTRs)
  - Bilateral market

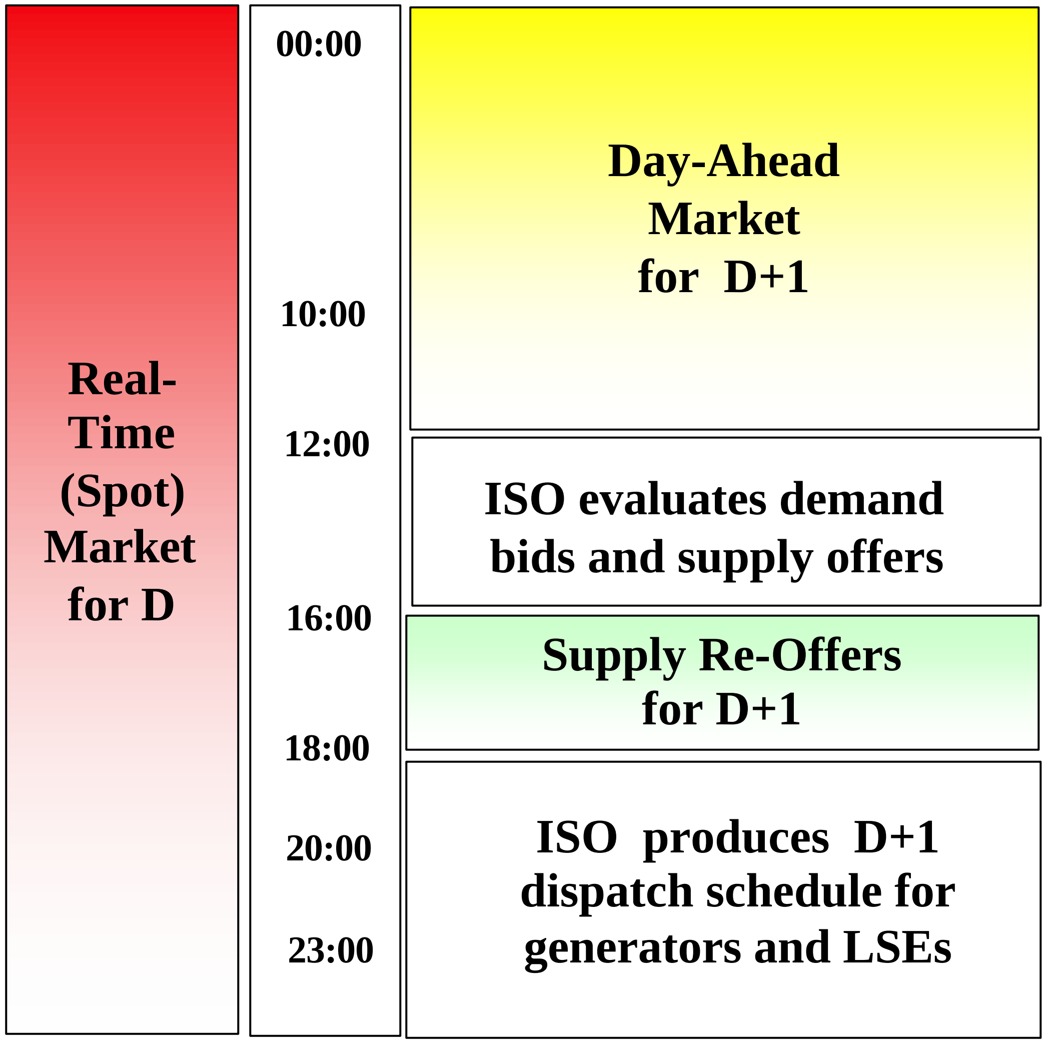
5-Bus Demo Model



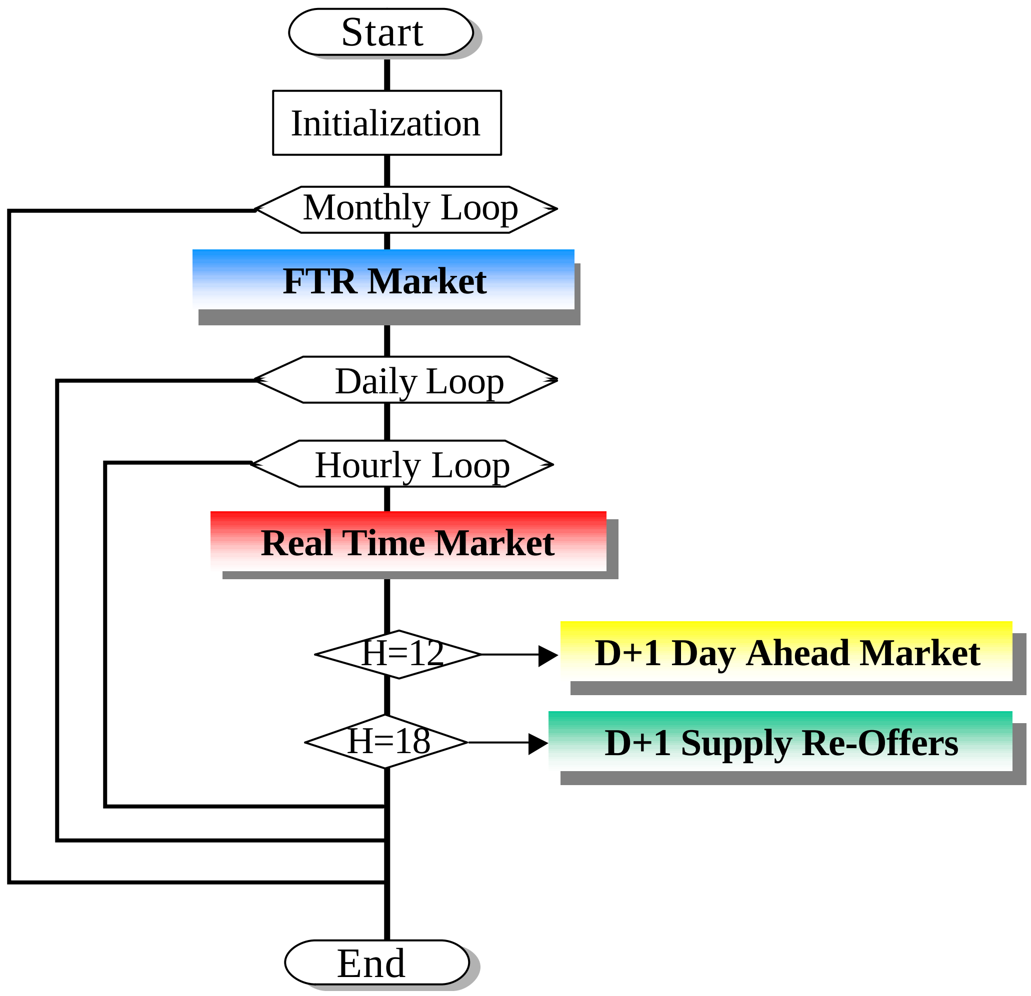
ACE WPM Model: Class Hierarchy



ISO Market Operation (Day D)



ACE WPM Model: Activity Flow



Initial Experimental Design: Treatment Factor Ranges

- Simple reinforcement learning ➔ Learning to learn
- Passive demand ➔ Active demand bidding
- No transmission rights ➔ Point-to-point financial transmission rights

Longer-Run Research Plans

- Collaboration with Los Alamos National Lab energy researchers
- **Objectives:**
  - To scale up ACE wholesale power market model to more realistic dimensions
  - To incorporate ACE wholesale power market model into the LANL Marketecture Model for U.S. Energy Infrastructure