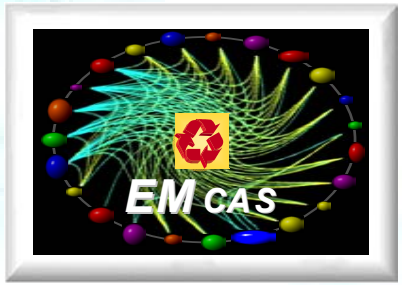
Simulating the Behavior of Electricity Markets with an Agent-Based Methodology:

The Electricity Markets Complex Adaptive Systems (EMCAS) Model



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Energy Markets in Turmoil: Making Sense of it All

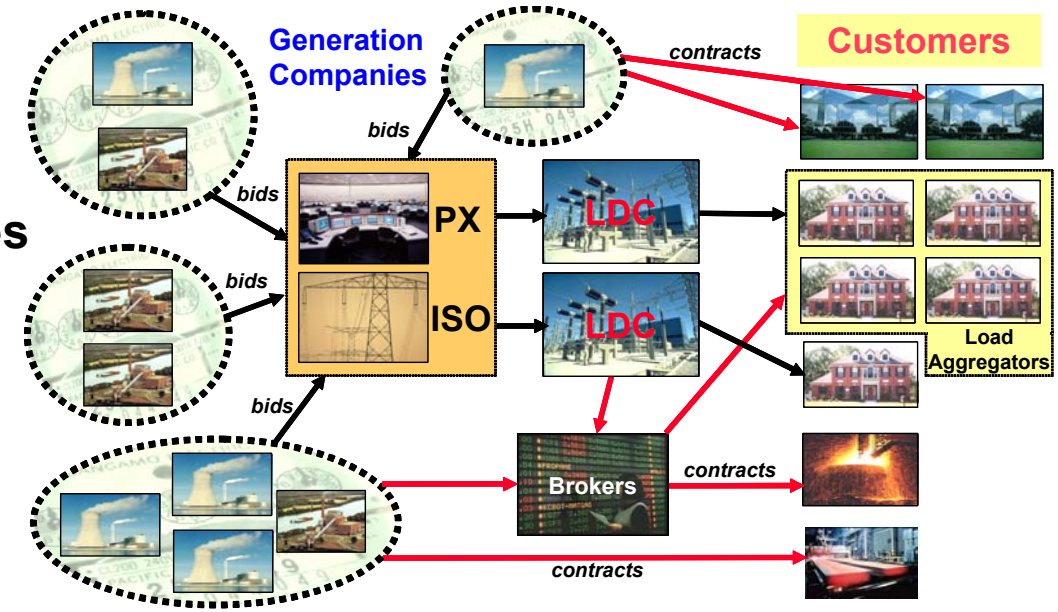
Electricity Markets are Changing

- **The old regulated markets emphasized centralized decision-making; Argonne has used a variety of conventional approaches over the last 25 years to successfully model these markets in more than 40 countries**

- **The new deregulated electricity markets are founded on decentralized competitive decision-making**
  - Markets have greater complexity
  - Markets have more players
  - Participants have different (often conflicting) objectives and decision characteristics or risk preferences

- **Conventional modeling approaches must be extended to account for the new reality of decentralized competitive decision-making**

- **These extensions must be complementary to existing approaches**



EMCAS is Designed to Address the Complexities in the New Markets

- **EMCAS uses a new analysis technique - agent-based modeling and simulation (ABMS)**
- **ABMS is related to other simulation techniques**
  - Game theory
  - Discrete event simulation
  - Distributed artificial intelligence or multi-agent systems
- **ABMS has been used successfully to model decentralized competitive decision-making in other domains**
  - Financial markets
  - Supply chains
  - Transportation systems
  - Social sciences
  - Biological sciences

ABMS Focuses on Individuals

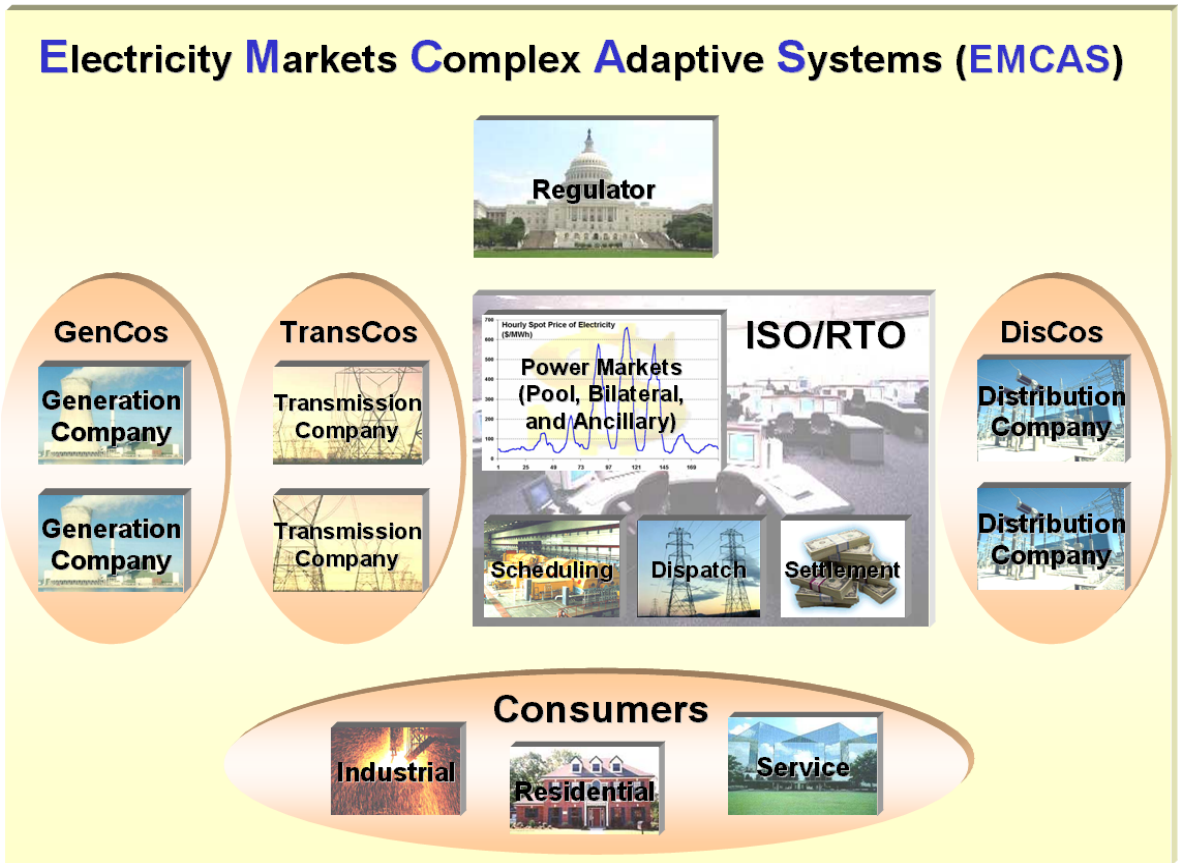
- **ABMS uses sets of agents and a framework for simulating their decisions and interactions**
- **An agent is a software representation of a decision-making unit**
- **Agents are *self-directed objects* with specific individual traits**
- **Agents typically exhibit bounded rationality, meaning that they make decisions using limited internal decision rules that depend only on imperfect local information**
- **Agent frameworks allow groups of agents to interact in complex, dynamic ways**
- **Agents operating within an agent framework can be used to model decentralized competitive decision-making**

EMCAS Combines ABMS with Several Modeling Techniques

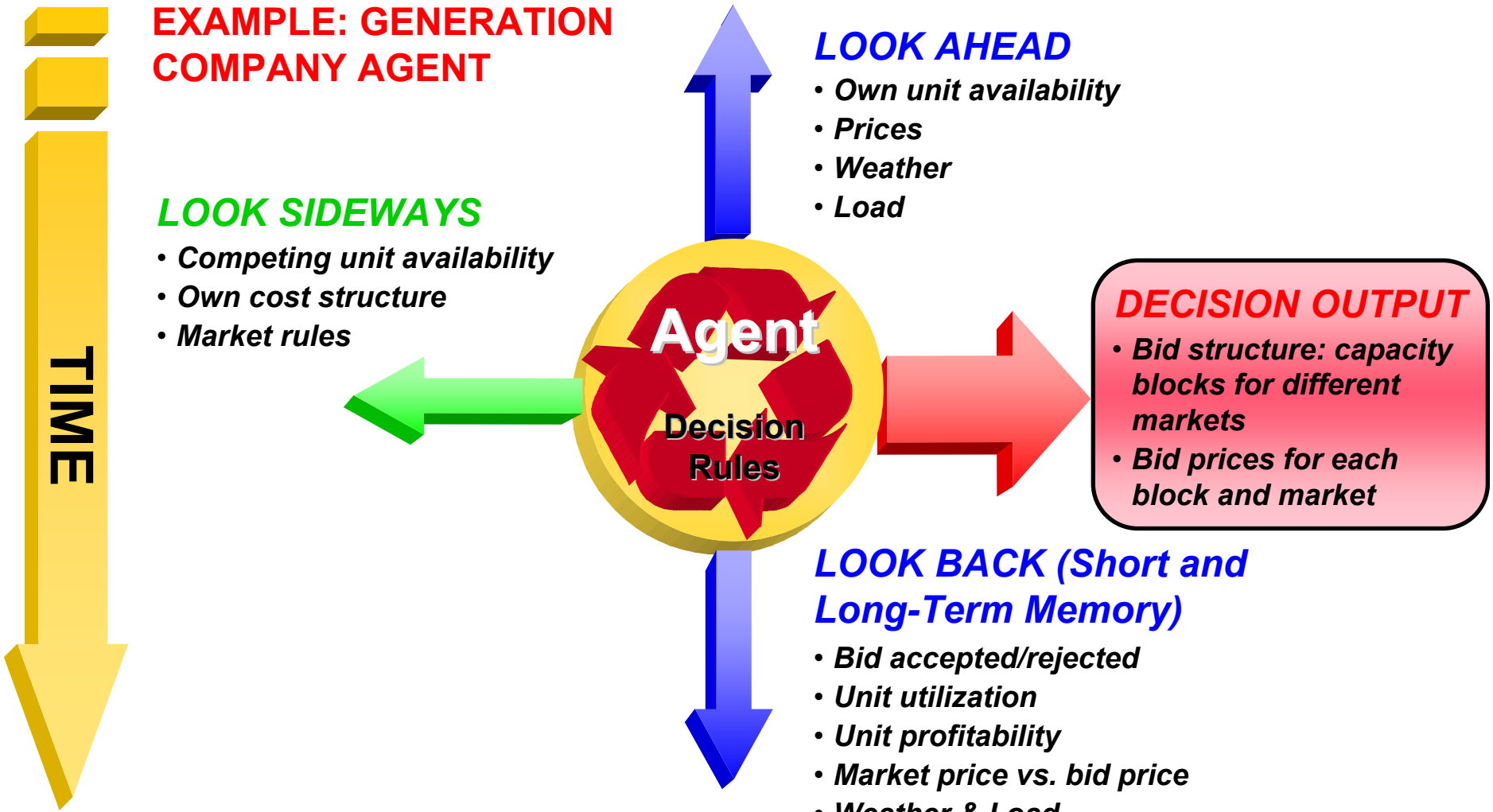
- **Utility function characterization of agent objectives**
- **Heuristic optimization for unit commitment**
- **Demand response functions**
- **Transmission load flow analysis**
  - ECMAS ISO/RTO agents use both Newton-Raphson and fast decoupled load flow solvers for AC power flow modeling
  - Transmission network reduction

EMCAS Uses A Variety of Agents to Model Decentralized Electricity Markets

- **Physical agents**
  - Generators
  - Transmission buses
  - Transmission lines
- **Decision-making agents**
  - Consumers
  - Demand agents
  - Distribution companies
  - Generation companies
  - Transmission companies
  - ISO/RTOs
  - Regulators

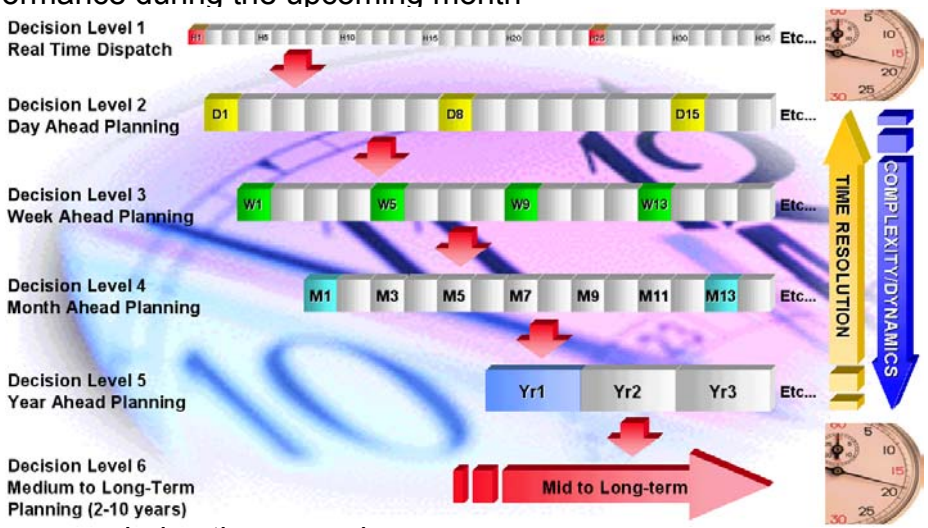


EMCAS Agents Make Decisions Based on Both Past Experiences and Future Expectations



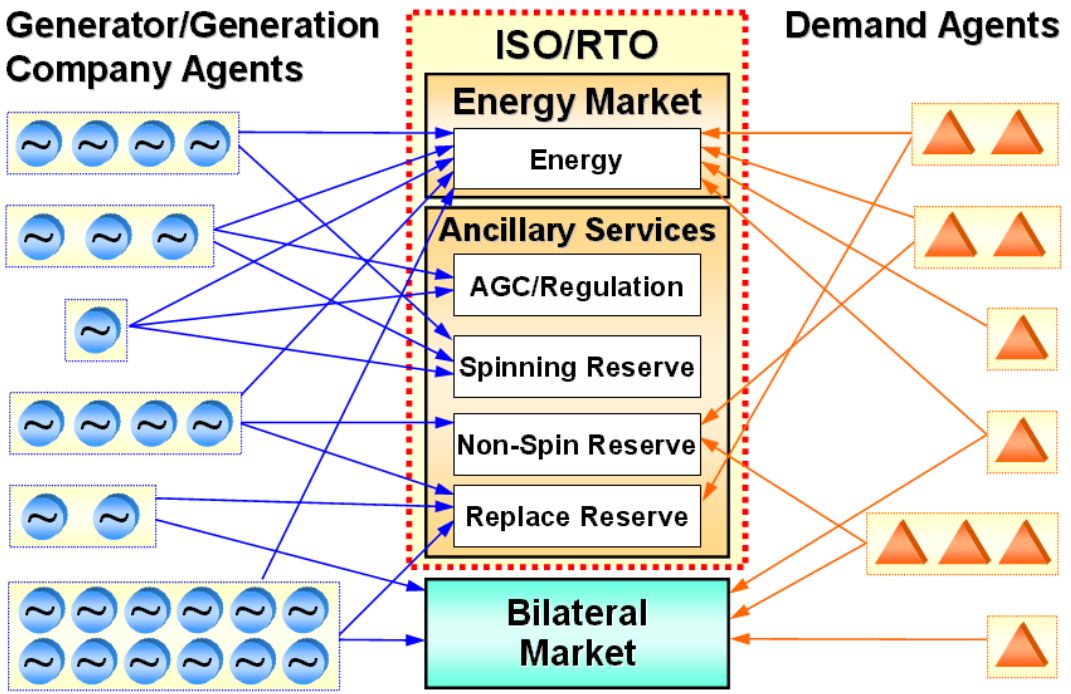
EMCAS Operates at Six Time Scales or Decision Levels

- ***Hourly/Real-Time Dispatch:***
  - Power plants are operated as directed by the ISO in accordance with prior market arrangements made under bilateral contracts and in energy and ancillary service markets
- ***Day-Ahead Planning:***
  - Agents determine market allocations for selling products
  - Bilateral contracts are formed with individual demand agents, and energy bids are sent into the ISO
  - Agents make unit commitment schedules for the next day
- ***Week-Ahead Planning:***
  - Weekly bilateral contracts are made with individual demand agents and are sent to the ISO for approval
  - Day-ahead marketing strategies are adjusted
- ***Month-Ahead Planning:***
  - Monthly bilateral contracts are made with individual demand agents and sent to the ISO for approval
  - Adjustments can be made to unit maintenance schedules
  - Month-ahead marketing strategies are adjusted to improve performance during the upcoming month
- ***Year-Ahead Planning:***
  - Monthly bilateral contracts are made with individual demand agents and sent to the ISO for approval
  - Planned maintenance schedules are determined
  - Month-ahead marketing strategies are adjusted to improve performance during the upcoming year
  - The corporate utility may also be adjusted
  - New construction schedules are revised
- ***Multi-year Planning:***
  - Agents make multi-year bilateral contracts
  - Capacity expansion plans are formulated
  - Year-ahead marketing strategies are adjusted to improve performance during the upcoming year



EMCAS Incorporates Several Markets: Bilateral, Pool Energy, and Ancillary Services

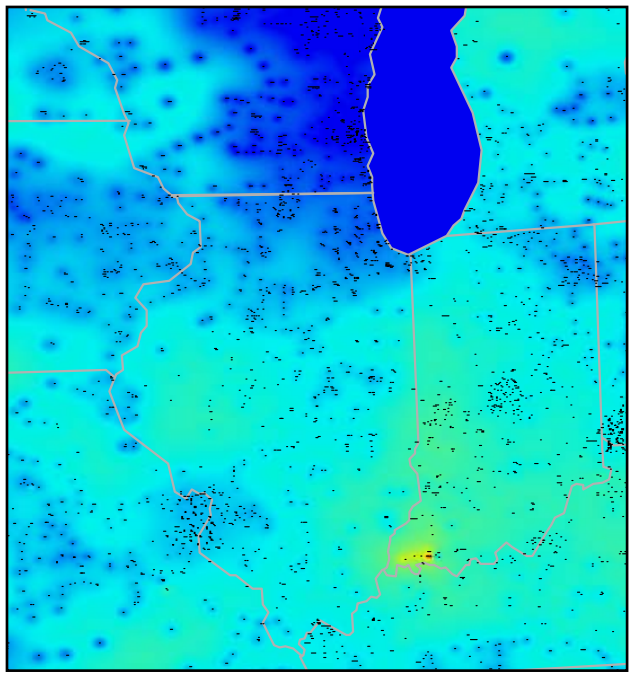
- **Bilateral contract markets are modeled at the daily, weekly, monthly, yearly, and multiyear levels**
- **Pool markets are modeled at the daily level**
- **Ancillary markets are modeled at the daily level**
- **Different EMCAS agents use different market participation strategies that vary over time:**
  - For example, only a fraction of the EMCAS generation company agents typically make adjustments to week-ahead strategies at any one time
  - In addition to scheduled decision making, strategies may be adjusted or new strategies may be explored
  - Adjustment and exploration is done more frequently under stressful conditions



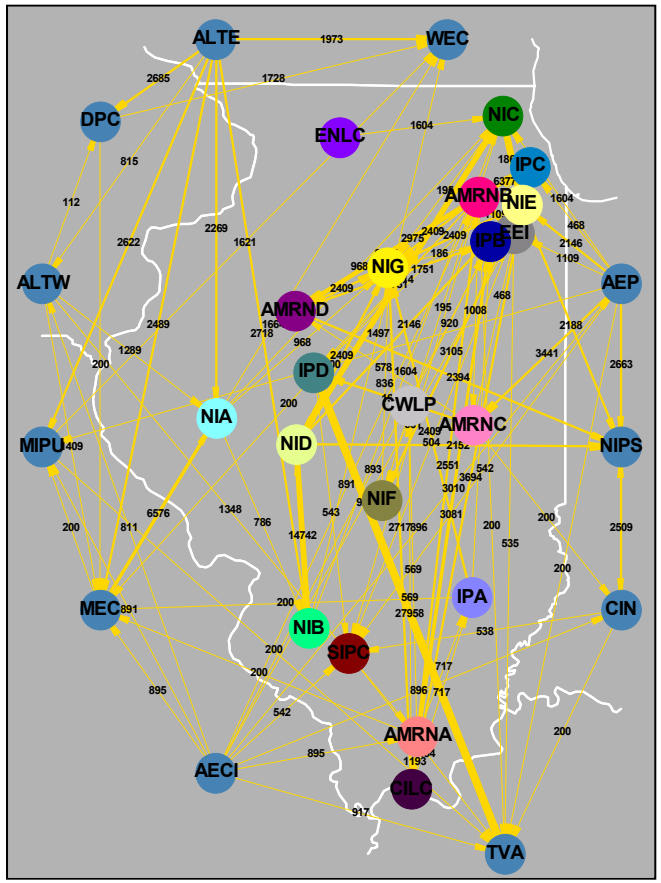
In EMCAS, the Physical System is Represented at the Bus/Branch Level while a Network Reduction Allows Zonal Market Simulation

- Argonne Load Flow (ALF) module offers a set of network reduction tools that find smaller but equivalent representations of large networks

- EMCAS uses the same reduced transmission network in its simulation until major topology changes (e.g., substantial line outages) require network reduction to be rerun

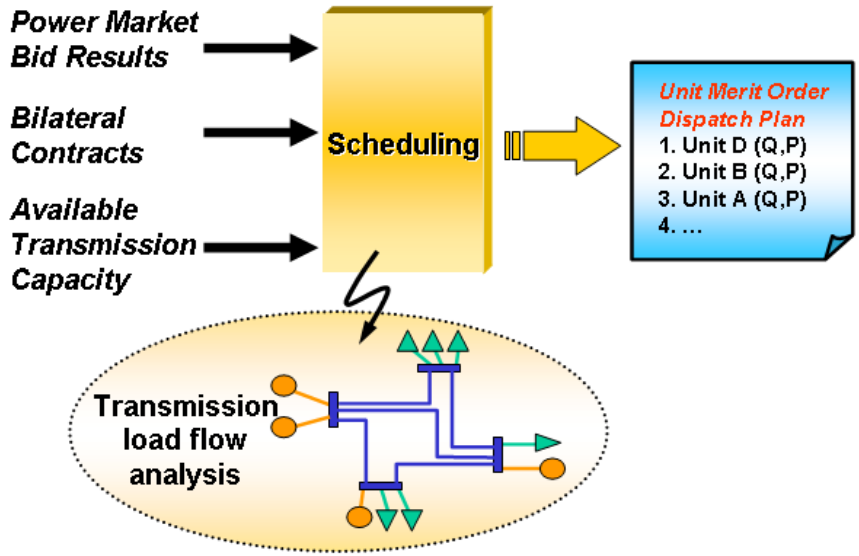


Network Reduction from Bus-Level to Zonal Level



The EMCAS ISO/RTO Agent Performs Several Functions

- ***Projection function***
  - Forecasts next day weather, system demand, and system available generation capacity
  - Makes information available to all agents
- ***Pool market function***
  - Operates the pool market for energy and ancillary services
- ***Scheduling function***
  - Accepts or rejects pool market bids and bilateral contracts using conventional load flow and optimization tools

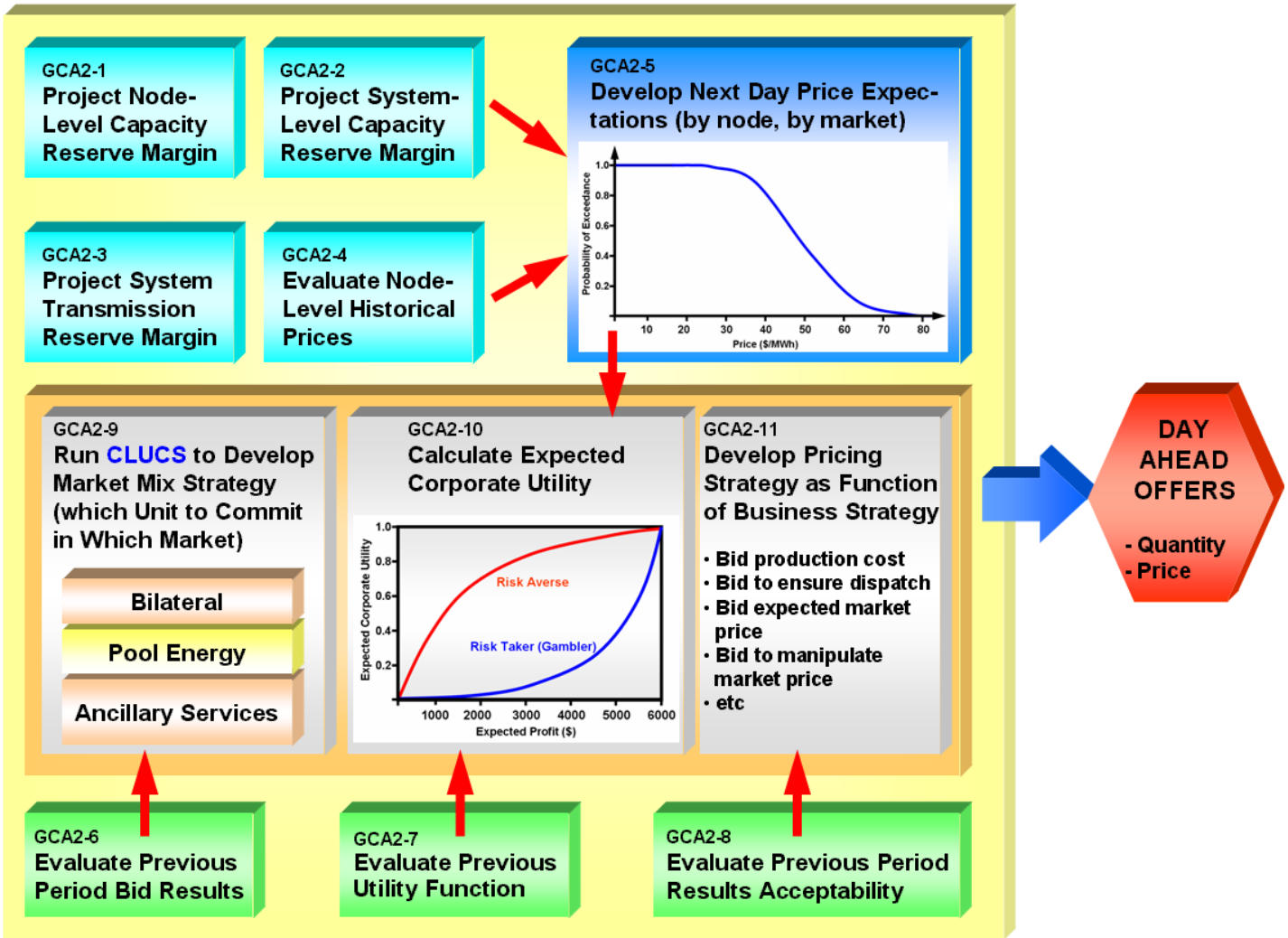


- ***Dispatching function***
  - Dispatches the generators in real time to match the demand
  - Maintains the necessary security requirements
- ***Settlement function***
  - Applies settlement rules selected by the user to calculate the payments to and receipts from the generating companies, demand agents, and transmission companies

The EMCAS Regulator Agent Establishes the Prevailing Market Rules

- The EMCAS regulator agent can specify a variety of ISO/RTO operating rules to study the impact of various policy issues on market performance
- Allows to set the required levels of regulation, spinning, non-spinning, and replacement reserves
- Allows to choose among different price setting rules such as LMP pricing or pay-as-bid pricing
- Allows to choose settlement rules for the energy market, the ancillary service markets, and transmission service markets

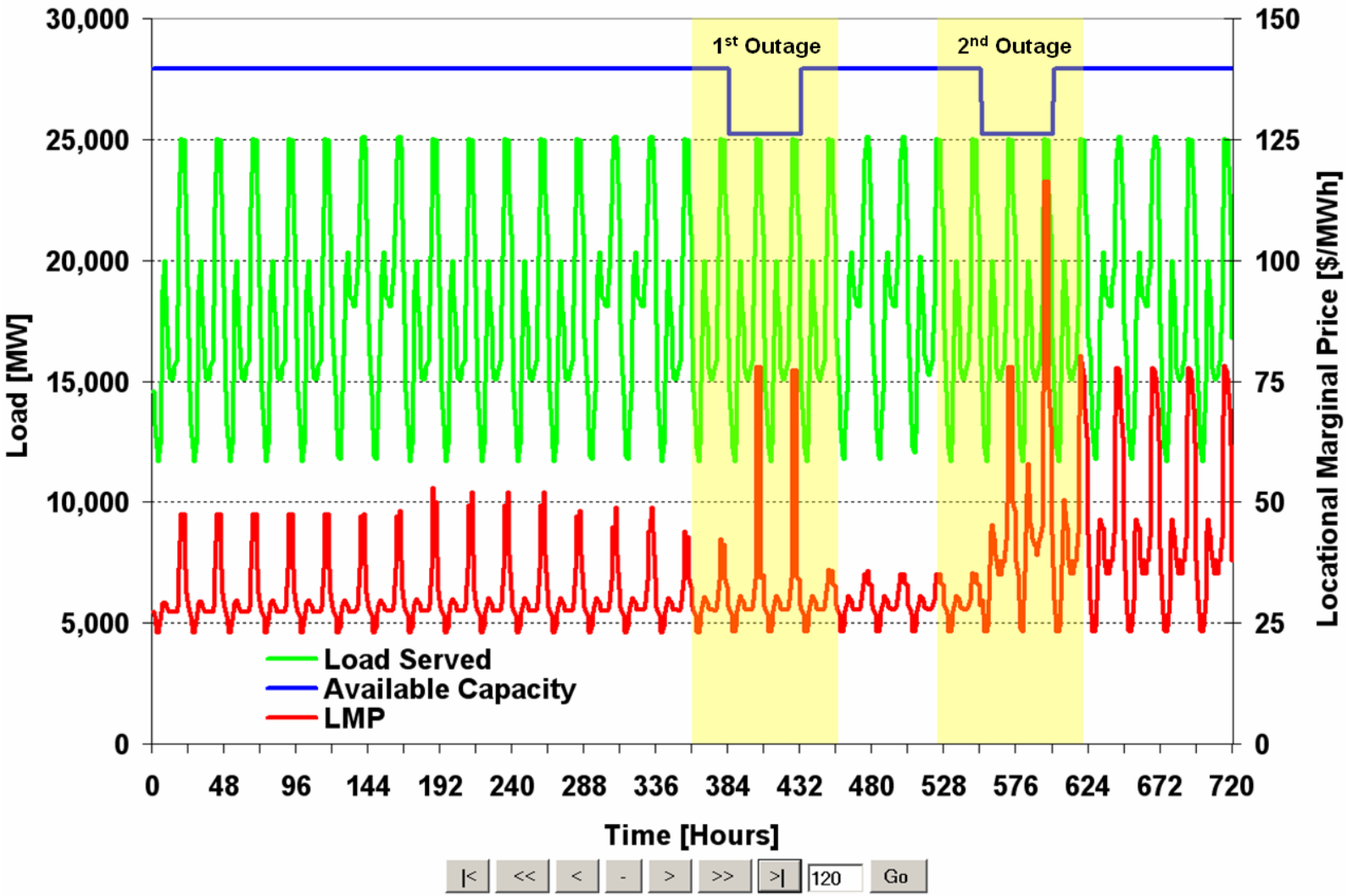
EMCAS Generation Company Agents Use a Sophisticated Decision Process to Address Market Complexity



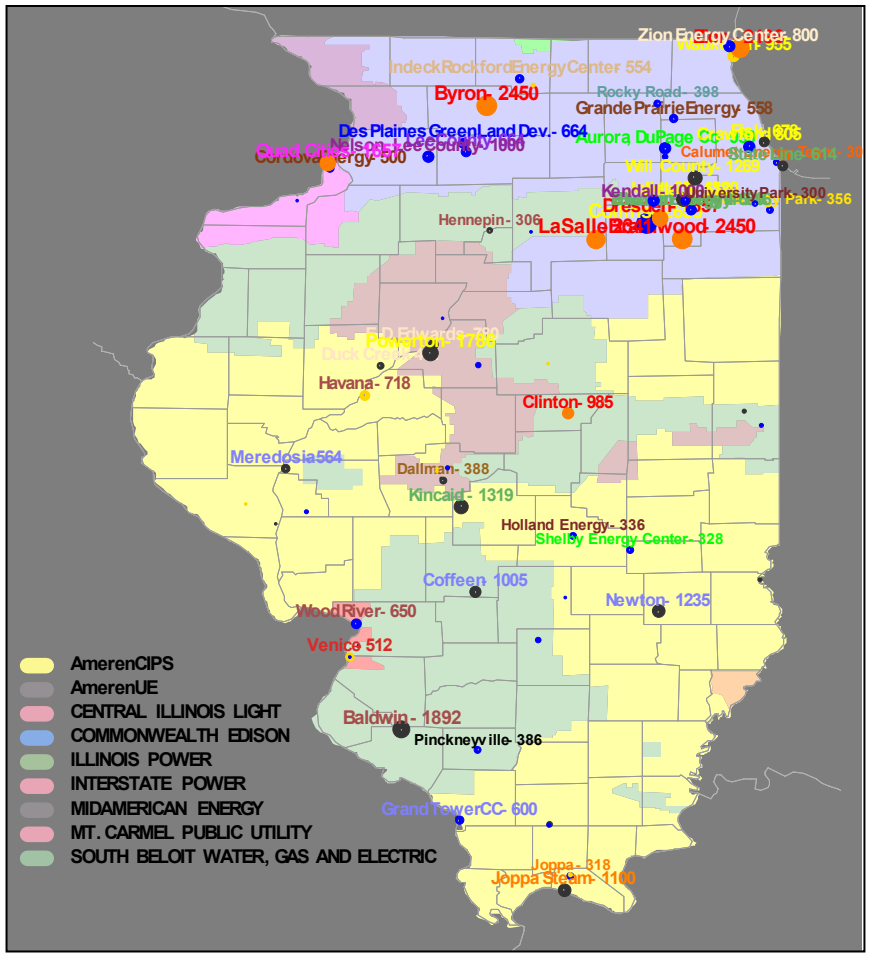
EMCAS Generation Company Agent Strategies are Based On Several Factors

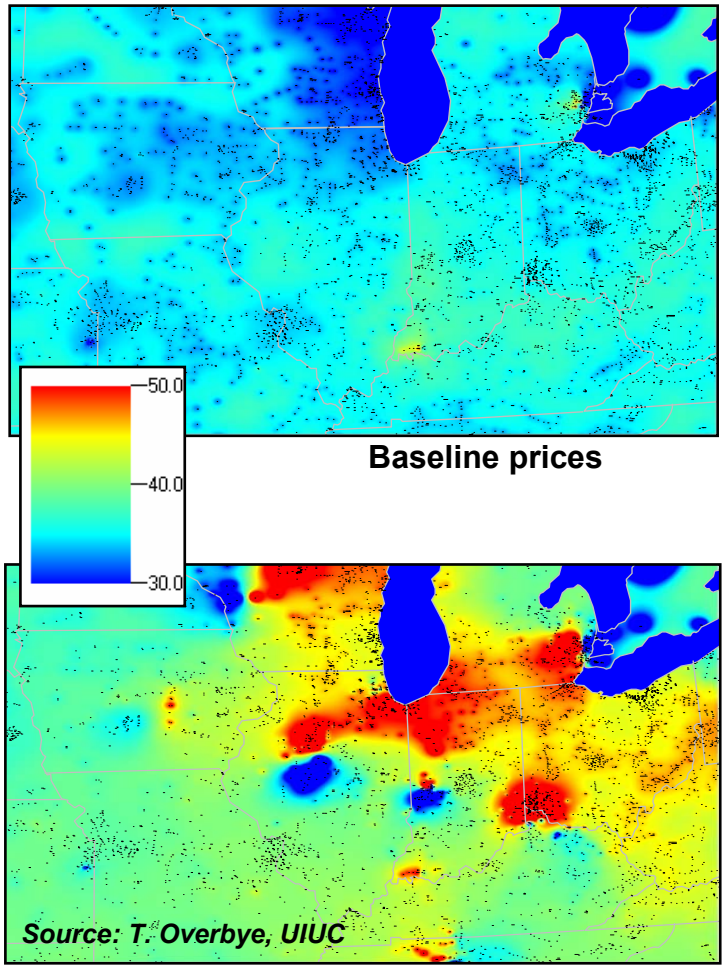
- **The success of generation company agent strategies is not guaranteed; agents weigh the relative rewards of success against the costs and risks of failure**
- **The anticipated success or failure rate is based on experience:**
  - Each generation company agent keeps an ongoing private record of historical events (i.e., private memory) including a history of strategies employed in the past and how well strategies performed under various supply and demand conditions
  - Information such as system outages, loads, locational market prices are posted by the ISO on publicly available bulletin board
- **The level of risk that an agent is willing to take is an integral part of its decision making:**
  - More conservative agents that have a lower tolerance for risk may have lower profits but have a steady stream of income
  - More aggressive agents may have the potential for higher profits but experience financial failure if anticipated market behaviors do not come into fruition
- **Some business strategies that the generation company agent can consider**
  - Bid on contracts or bid into the pool market
  - Bid into the energy market and/or the ancillary services market
  - Adjust/change bid price strategy (production cost, low bid to ensure acceptance, bid high on last portion of capacity, withhold capacity)

An EMCAS Simulation Showed that the Generation Company Agents "Learned" to Increase Prices During an Outage



Argonne is Working with the University of Illinois to Evaluate the Potential Impacts of Transmission Constraints on the Operation of a Competitive Electricity Market in the State using EMCAS





Baseline prices

Effect of one company increasing prices

Cheaper sources of electricity may have problems moving power to load centers because of transmission constraints

EMCAS Can Be Used As An E-Laboratory to Model the New Decentralized Electricity Markets

- **As electric utility systems around the world continue to move toward open, competitive markets, the need for new modeling techniques will become more critical**

- **Although traditional optimization and simulation tools will continue to provide many useful insights into market operations, they are typically limited in their ability to adequately reflect the diversity of agents participating in the new markets, each with unique business strategies, risk preferences, and decision processes**

- **Rather than relying on an implicit centralized decision maker, ABMS tools such as EMCAS can be used as electronic laboratories (e-laboratories) to model decentralized power markets and**
  - To test market configurations
  - To test market strategies of the various participants
  - To identify regions of stability, transients, and chaos
  - To evaluate options to manage the market effectively

In Summary, there are Multiple Advantages to the EMCAS Agent-Based Simulation

- Decentralized decision making is represented
- Alternative company strategies can be simulated
- Learning and adaptation occurs in the simulation
- Market rules can be tested
- Transient conditions can be studied
- Contributors to system problems can be identified