# Validation of an Agent-based Model of Deregulated Electric Power Markets

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**Abstract**

EMCAS (Electricity Market Complex Adaptive System) is an agent-based simulation model of the electric power market designed to investigate market restructuring and deregulation and to understand the implications of a competitive power market on electricity prices, availability, and reliability. Model validation is an essential parts of the model development process if models to be accepted and used to support decision making. This paper describes the validation process for the EMCAS model. Motivation for this study was based on the need to establish credibility for the EMCAS model and its results for use in practical decision making. The validation process also is an initial attempt to establish a general and practical framework for agent-based model validation.

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EMCAS (Electricity Market Complex Adaptive System) is an agent-based simulation model of the electric power market designed to investigate market restructuring and deregulation of the power market and to understand implications of a competitive market on electricity prices, availability, and reliability. This paper describes the validation process for the EMCAS model. Model validation is an essential parts of the model development process if models to be accepted and used to support decision making. One of the very first questions that a person who is promoting a model is likely to encounter is "has your model been validated?" If the answer to this critical question is "no," experience has shown that the model is unlikely to be adopted or even tried out in a real-world setting. The challenge for validation then becomes one of being able to say "yes" to this critical question "Have you validated your model?" Motivation for this study was based on the need to establish credibility for the EMCAS model and its results. The validation process also is an initial attempt to establish a general and practical framework for agent-based model validation.

## EMCAS Model

The agents in EMCAS represent the participants in the electricity market. Different types of agents are used to capture the heterogeneity of restructured markets, including generation companies (GenCos), demand companies (DemCos), transmission companies (TransCos), distribution companies (DistCos), independent system operators (ISOs), consumers, and regulators. The agents are specialized and perform diverse tasks using their own decision rules. Agents can learn and adapt about the market and the actions of other agents. Agents constantly explore new strategies in an attempt to adapt to the dynamic and evolving supply and demand forces in the marketplace, and to search for strategies that perform better. Through this process, agents engage in a price discovery process and learn how they may potentially influence the market through their own actions to increase their own utility. The EMCAS model is described elsewhere from various technical perspectives including the benefits of agent-based modeling in the context of deregulated electric power markets [North et al., 2002; Macal et al., 2004; Conzelmann et al., 2004; Koratarov, 2004].

Model validation immediately touches on the fundamental issues of the relationship between modeling and science and the purpose of modeling. Can we purport to learn anything about the real-world from modeling? Is the purpose of a model to predict the future with a high degree of accuracy, to gain insights into the workings of a process, or to identify areas of greatest uncertainty? The purpose of EMCAS is not necessarily to predict the future, but rather to provide insights into the possible evolutions of the electric power markets under deregulation. Lempert, Popper & Bankes [2003] propose a framework for model analysis that does not purport to predict the future, but emphasizes the use of models in the context of robust analysis, designed to reduce uncertainty for decision making. Generally the purpose of modeling is not to create an exact representation of all of details of a system. Carley [2002] addresses the essential tension that necessarily occurs in modeling any system between model transparency (less detail) and veridicality (more detail) due to the fact that all models are necessarily approximations to the real world. Because of the enormous complexities of the electric power market in terms of its technical nature and purported behaviors of economic agents in an environment that does not currently exist, EMCAS is designed to include only the essential system details but enough details to have credibility with experts on the system.

## Validation Background

Traditional model validation has a rich tradition, is well-documented, and carries over into agent-based modeling. Traditionally, model validation consists of systematically comparing simulation model results to data coming from a real world system [AIAA, 1998; Balci, 1998; Bankes, 1993; Law and Kelton, 2000; Sargent, 2003]. Some work has extended traditional model validation approaches to the object-oriented paradigms [Yilmaz and Balci, 1997], as agents are objects with the additional feature of autonomous behavior. Validation issues and approaches for knowledge-based models, such as human behavior models [Harmon et al., 2002] or expert system models [O'Keefe & O'Leary, 1993], are also relevant. Burton [1998] address the benefits for using multiple models together for comparison purposes to address a specific problem in a process called model "docking." Axelrod [1997] states that "replication [of results from multiple models] is one of the hallmarks of cumulative science" and presents three bases for comparing models in descending order of severity: numerical identity, distributional equivalence, and relational equivalence. These comparisons are useful, however, even when the referent in question is the real-world or the subjective judgments of subject matter experts. Axtell, et al. [1996] provide a systematic analysis of the issues raised in trying to establish the equivalence between or the "alignment" of computational models that claim to deal with the same phenomena. Finally, Miller [1998] proposes systematic procedures to formulate models with the explicit intent to invalidate models, such as Active Nonlinear Tests (ANTs). Each of these aspects of validation is included in the framework for validating the EMCAS model.

## Case Example:
## Validation of the EMCAS Deregulated Electric Power Market Model

The EMCAS model deals with an important public policy issue, electric power market deregulation, in which virtually all segments of society, e.g., electric power producers, investors, electricity consumers, etc., have important economic interests. Therefore, the burden for validation of the model and its results is severe by most modeling standards. The modeling results must be able to withstand scrutiny and criticism from many parties having vested interests in what the model results may imply. Since the deregulated electric power market being modeled does not currently exist, validation of the model presented special challenges. Comparing EMCAS model results with the real-world deregulated system through formal statistical means was not an option, although the purely physical electric power grid models had been validated previously for the case of the regulated power market. How then can we validate the model in terms of supporting the contention that the model accurately portrays the future, at least a future that is conditional upon the explicit assumptions included in the model?

In the case of models that contain elements of human decision making, validation becomes a matter of establishing credibility in the model. Validation works by removing barriers and objections to model use. The task is to establish an argument that the model produces sound insights and sound data based on a wide range of tests and criteria that "stand in" for comparing model results to data from the real system. The process is akin to developing a legal case in which a preponderance of evidence is compiled about why the model is a valid one for its purported use. In this paper we describe a practical validation process as an extension to traditional model validation for use when the real-world system is not available. We construct a set of considerations and a process that allow us to construct an argument that the model has been validated. The elements of the validation framework are shown in Table 1. The result of the validation process is a set of resources that one may draw upon to counteract objections to the notion that the model is valid and produces valid results.

## Data Validation

A single data gap or inconsistency can invalidate the results of any model and destroy the model's credibility. Therefore, data validation is necessarily a part of the model validation process. The EMCAS database was assembled from several formally structured and generally available data bases. Each data base was generally in good condition, but not unexpectedly, gaps and inconsistencies in the data were apparent upon cursory inspection. Data ages quickly in some cases, and it may no longer be current. The data was checked for currency as it was assembled in the EMCAS database. Combining data from different data sources into the EMCAS database created additional complexities owing to the need to map and cross reference data field definitions and convert to common units to ensure consistency. Careful iterative analysis was done to resolve gaps and inconsistencies in the data. A period of several months was required to iteratively refine and update the EMCAS database on a largely unpredictable time scale, delaying progress in the main modeling effort. Ultimately, all data uncertainties, anomalies, and questionable values were resolved, establishing a sound data foundation for the EMCAS model.

Cross-checking the data with third parties having a vested interest in the accuracy of the data was another aspect of validating the EMCAS database. Parties who are the closest to specific data elements, such as planned expansions of generation capacity by generating companies, are the most likely sources of objections to the data used in the model. These groups were engaged in the data validation process to ensure that the most current data available was being used and to elicit their concerns and objections early on. In addition, some proprietary data was provided by vested third parties. Proprietary data included operational data for individual generating companies such as plant heat rates and operating costs. These data were assumed to be correct and accurate and outside of the data validation process.

- **Data Validation**
    - Data Gaps and Inconsistencies
    - Data Currency
    - Third-Party Data Verification
    - Proprietary Data
    - Data Visualization
- **Subject Matter Expert (SME) Judgment**
    - Developer SMEs
    - Independent SMEs
- **Participatory Simulation**
- **Model-to-Model Comparison**
- **Critical Tests and Key Indicators**
- **Comprehensive Test Cases**
    - Parameter Space
    - Agent Strategies
- **Invalidation Exercises**

**Table 1: Model Validation Framework**

Extensive use of sophisticated visualization techniques also proved very useful in visualizing the data and identifying data anomalies that were not otherwise apparent. Data gaps and inconsistencies were easily spotted through the visualizations.

## Role of Subject Matter Experts

The EMCAS model was developed by a team of experienced subject matter experts (SME) consisting of electric power engineers, systems engineers, and economists. This proved critical to establishing a baseline model with a rich set of realistic system characteristics and recognizable from a variety of perspectives. The developer SMEs had extensive experience in electric power system operations and operational economics, as well as in modeling the electric power system and experience in making the required veridicality/transparency tradeoffs.

Independent subject matter experts (i.e., independent of the model developers) were used to evaluate the scope and detail of the model during the critical design phase, reviewing model assumptions, preliminary results, and purported agent behaviors. A workshop was held for SMEs from the electric utility industry, which included former utility operators, industry consultants, and electric power market traders. The independent SMEs had little vested interest in the correctness of the model's assumptions if they were at odds with personal and industrial experience. The independent SMEs also had the ability to place themselves in the positions of agents in the deregulated markets, based on their work experience. The SMEs provided constructive critiques of relevant agent behaviors and validated (or invalidated) previous assumptions. In the latter phase of the EMCAS model application, SMEs raised questions on the EMCAS system-wide results and provided insights for explaining model behaviors (validation) or identifying cases that indicated underlying model weaknesses (invalidation).

## Participatory Simulation

In advance of the modeling effort it proved to be very insightful to run a "participatory simulation" with real people playing the roles of the agents in the deregulated electric power market. The participatory simulation served to validate key assumptions on agent behaviors in a deregulated environment, such as how quickly agents created and learned profit maximizing strategies. It also identified likely strategies the agents would use in various situations, what information was most useful to the agents, and bounded the decision problem by practical considerations. It revealed how much information was possible to process and make decisions about in a given time frame. Since the electric power system, even in an idealized modeling situation, presents decision makers with an enormous amount of information at any given time, it was observed that decision makers tend to focus on a few key indicators and build strategies around those variables. It should be noted that participants in such a participatory simulation need not be subject matter experts if the procedures and rules of the simulation are clearly stated to the participants. It is often preferable to include non-SMEs for the sake of increasing the diversity of the strategies that participants create during the simulation. Figure 1 shows the results of a validation exercise in which results from an EMCAS simulation were compared to the results obtained from a participatory simulation.

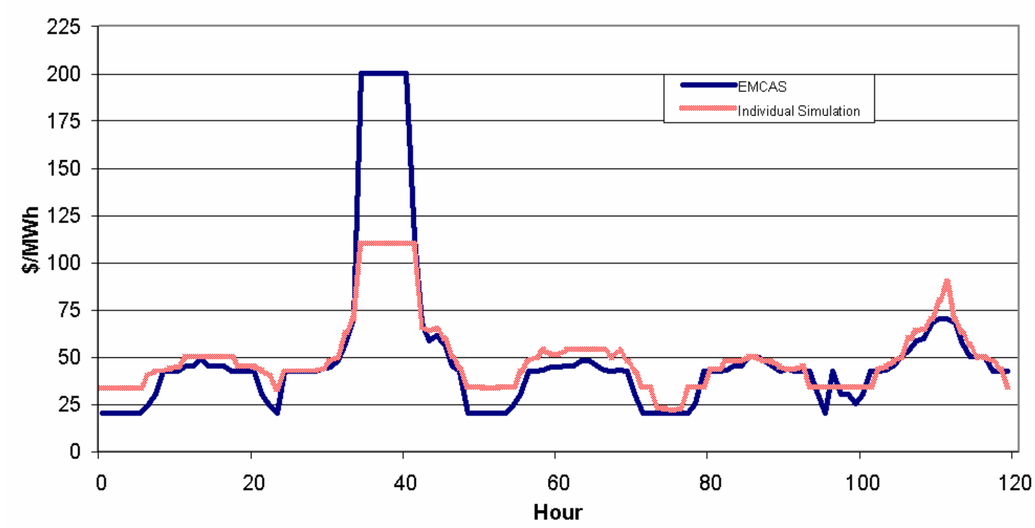


**Figure 1: EMCAS Closely Matched Results of a 6-Player Participatory Simulation**

## Critical Tests and Key Indicators

One mode of validation is to see how well the model performs at reproducing system behaviors for a specific set of critical test cases and examine key indicators upon which to judge model validity. Three critical test cases were identified: (1) replication of the known results for the current regulated electric power market configuration, (2) emergence of so-called hockey stick strategies adopted on the part of generating company agents as the agents in the deregulated simulation learned to responded to market incentives, and (3) replication of elements of the system behaviors reminiscent of the California electric power deregulation situation. The EMCAS model reduced to a centrally planned, regulated electric power market configuration under a specific set of assumptions regarding the agent behaviors. These included the agents always bidding at long-run marginal production cost. Many years of data exist for the regulated market configuration and virtually all models of the electric power system in use today have these built-in assumptions. Under the most common types of bidding rules for deregulated electric power market, it has long been theorized and verified in non-computational participatory simulations that the profit-maximizing /risk-reducing bidding strategy is one in which generating company agents bid low on their base generating capacity to ensure dispatch and bid very high on generating units that may be the marginal producers for the entire electric power market. The emergence of these so-called hockey stick strategies in the EMCAS model was a key validation test. Finally, the California experience in electric power deregulation of a few years ago provided key indicators against which the results of EMCAS could be compared, such as runaway agent bid pricing in the face of system reserve margins that were negligible.

## Model-to-Model Validation

The EMCAS model had two other models against which its results could be compared in the interest of validation: (1) a model of a centrally planned, regulated electric power market configuration, as discussed above and (2) a more detailed and complete alternating current (AC) model of the physical aspects of the electric power grid. The EMCAS model subsumed the regulated electric power market model. This allowed EMCAS to be validated for one special case of its operational parameters. Validation of the EMCAS reduced form direct-current (DC) model of the electric power grid was also necessary. The DC model was only an approximation over a local range of operating parameters to the physically complete AC model. The AC model had been validated against the actual physical power grid in numerous validation exercises that had been conducted over the years. Computational limitations precluded incorporating the AC model directly into EMCAS and necessitated the DC approximation. Validation of the DC model to the AC model was done by comparing results for a number of key cases from the DC model to the full AC model solution.

## Comprehensive Testing

Comprehensive testing of plausible electric power agent strategies revealed that it was not possible to draw general conclusions from only a handful of model runs because of the non-linear, dynamic aspects of the agent behaviors and interactions. The entire space of plausible agent strategies and parameter settings had to be mapped. There was at least some pre-defined structure to the boundaries of the strategy space with respect to validation. There is a set of agent strategies that are particularly important to understand. These include agent strategies that are both observed in practice and those that could be logically expected to be followed, for example, based on the rational choice model of the agent that dictates profit maximizing behavior. The basic notion of deregulation of the electric power market is that a free market will be self-correcting – higher prices will encourage new investment and innovation, foster a competitive environment, and in the long-run lead to economically efficient outcomes for both producers and consumers. This is an important area for the agent model to investigate in the context of the ability of the agents to respond and adapt their behaviors in this new, unconstrained environment.

In the most general terms for characterizing agent strategies under the assumption of rationality, generating company agents construct rational strategies to explore the price/quantity space in terms of the generating capacity to offer (bid) into the market and the price at which to offer the capacity. The strategies are designed to incrementally increase (rather than maximize) profits as compared to a reference state of profits, such as the profits obtained from the previous round of bidding. Various strategies are implemented in the price/quantity space for which agents were assumed to operate. Strategies included bid all capacity at production cost (the long-run theoretical market clearing strategy), physical withholding (reducing bid quantity at given price levels), economic withholding (increasing price levels for given quantities), price probing (exploring the effects of raising prices incrementally above recent bid price levels), and price discovery (exploring the effects of raising prices incrementally above hypothesized levels for marginal suppliers). Within each of these strategies, a family of plausible agent sub-strategies was constructed based on variations in parameter settings and detailed assumptions about how agents perceive their positions in the market.

## Invalidation Exercises

Since no model can ever be validated with complete certainty, validation exercises essentially consist of a series of attempts to "invalidate" a model. But this invalidation process can be done systematically rather than on an ad hoc basis to avoid validation bias. Validation bias is the tendency to only perform validation tests that are likely to validate the model, rather than tests that are just as likely to invalidate a model. Active efforts should be employed in an attempt to invalidate the model rather than simply constructing a set of arguments that support the validity of the model at the expense of ignoring potential cases that could invalidate the results. Extensive model runs served the multiple purposes of verifying model behaviors that were expected, thereby increasing the confidence in the model, discovering model behaviors that were outside the range of what was expected, and invalidating the model's assumptions. Discovering cases for which model behaviors were unexpected created focal points for more in-depth analysis and explanation.

## Lessons Learned

The path to EMCAS model validation is a work in progress. The model validation phase, because of the critical necessity dictated by policy analysis requirements of having a validated model has ended up taking as long as the model development phase. As each step in the validation process (shown in Table 1) was completed, the model was better accepted as a valid tool for answering important questions on aspects of electric power deregulation. Some important lessons learned are as follows.

1. It is relatively easy to convince decision makers that an agent-based model could be relevant and useful because it considers adaptive agent behaviors that clearly embody how agents behave in the real world. It is much more difficult to credibly characterize that behavior, explain it, and validate it.
2. Agent models, because they are highly disaggregate and built from the ground-up, contain more assumptions and data than traditional models. There is a lot of explaining to do to decision makers about agent behavior and adds to the burden of validation.
3. When explaining the agent strategies to decision makers, certain questions seem to repeatedly arise: Are all the relevant agent strategies considered? Why is the model attributing certain strategies to some agents and not to others? Why do all the agents adopt the same strategy (clearly not realistic)?
4. In the final analysis, all model results had to be explainable in plain English and the reasons for why seemingly counter-intuitive results were obtained had to be easily explainable, or they were not credible or useful to decision makers.

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