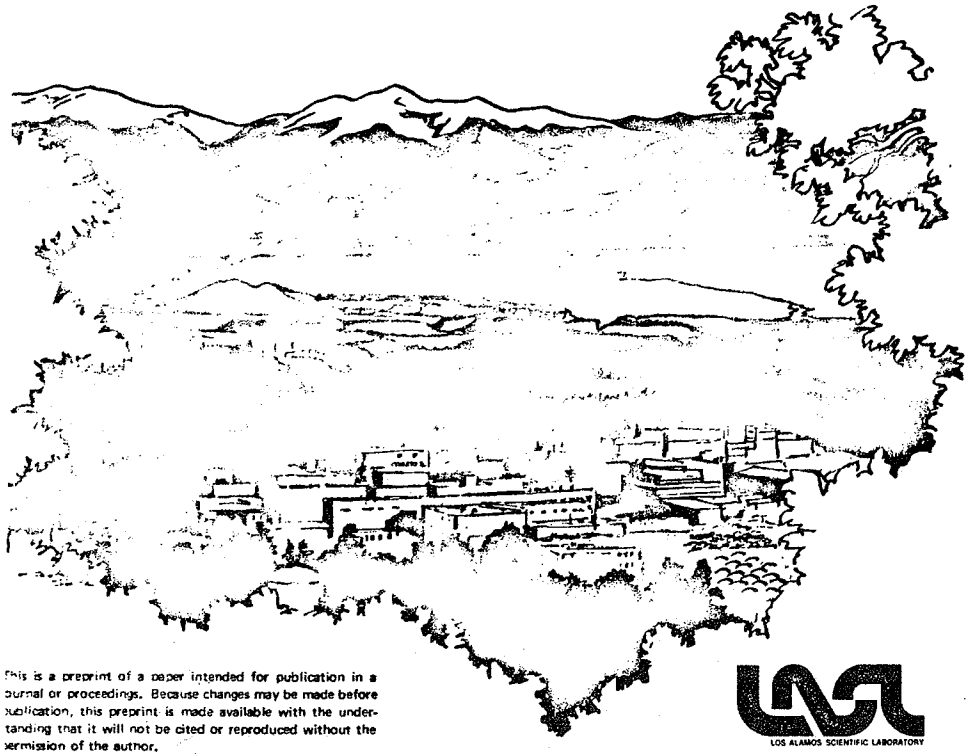
LA-UR-81-2262

TITLE: LESSONS FROM CASE 1454

AUTHOR(S): Andrew Ford
Economics Group, MS-605
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

SUBMITTED TO: 1981 System Dynamics Research Conference
The Institute on Man and Science, Rensselaerville, New York
October 14-17, 1981



LOS ALAMOS SCIENTIFIC LABORATORY

LESSONS FROM CASE 1454

Andrew Ford
Economics Group
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

In the winter of 1974, the El Paso Electric Company was granted a Certificate of Convenience and Necessity for the construction of the Palo Verde Nuclear Generating Station near Phoenix, Arizona. Construction began in 1976, and in February, 1979, Case 1454 before the New Mexico Public Service Commission was initiated to consider the company's request to count Palo Verde Construction Work in Progress in their rate base. The company argued that its 600 MW share of Palo Verde was necessary if it was to satisfy demand at the lowest possible price to the consumer. Representing consumers in the southern part of New Mexico, the energy unit of the Attorney General's Office took the position that El Paso Electric Company was already over-invested in generating capacity and had no need for such a large share of the nuclear station. The Attorney General's Office suggested that electricity rates would be lower if the company were to sell part of its ownership in the nuclear plant. During February and March, 1979, the Attorney General assembled a case opposing the company's bid for higher rates. Part of the Attorney General's case rested on calculations from a System Dynamics

model of the electric utility industry. This paper reflects upon the hearings in New Mexico with an eye toward the suitability of System Dynamics models for such adversary proceedings.

The paper is organized in three parts. It begins with a brief review of the substantive exchange of views in the case, including the Company's position, the Attorney General's position, and the analyses and counter analyses presented in support of these positions. In Part Two, the paper describes the participants and the schedule of the hearings. It is argued that the rapid pace of the hearings and the background of the participants are important determinants of usefulness of System Dynamics models under adversary proceedings. The third part of the paper concludes with a discussion of the advantages and disadvantages of system dynamics under fast paced, adversary conditions.

ANALYSIS AND COUNTER ANALYSIS

Alternative Expansion Plans

Much of the analysis given in this case revolved around the relative merits of the two expansion plans shown in Fig. 1. This figure shows the capacity construction initiation rate for three units of the Palo Verde station with scheduled completion dates of 1982, 1984, and 1986. Plan One, the plan preferred by the Attorney General, called for the sale of the company share of units #2 and #3 while Plan Two, favored by the company, called for continued participation in 200 MW of all three of the Palo Verde units.

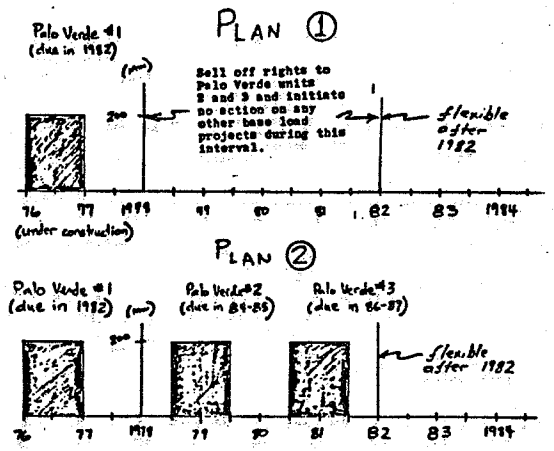


Fig. 1. Capacity initiation rates for alternative plans under discussion in Case 1454.

Notice that the capacity initiation rate in both plans is assumed to be flexible after 1982. Consequently, the plans may show differing capacity initiations in later years depending on the growth in demand in the El Paso Electric Company service area.

Uncertainty in Demand Growth Projections

It seems that all hearings on the relative merits of alternative utility expansion plans involve considerable discussion of at least two competing forecasts of the likely growth in electricity demand. The participants favoring large construction programs present a forecast for rapid growth in demand and usually arrive well prepared with data bases, econometric models, and witnesses to support the forecast. The participants arguing for a reduced construction program come prepared with their own forecast, data, models, and witnesses. The inevitable clashing of the two

groups arguing on behalf of different econometric forecasts usually consumes a good portion of the time and effort of all parties in the hearings.

In this case, the stage was set for such a clash. The company had forecast that the peak demand for power would grow at 6.7%/year, and the staff of the Public Utilities Commission in Texas has forecast a 3.9% annual growth. Rather than join in the battle over competing forecasts, my analysis was based on the premise that neither side can predict the future with certainty. This view was set out in direct testimony as follows.

> Q. What is the underlying premise of your testimony?
>
> A. My testimony is based on the premise that one cannot know the future. At best, one can only make projections about the future based on information available about the past. Projections, of course, can turn out to be incorrect and actions which are taken in reliance on those incorrect projections can involve significant costs or penalties. If an electric utility planner's demand forecast is too high, for example, the utility will likely be caught in later years with an over-investment in base load capacity. On the other hand, if the forecast is too low, the utility will not have enough base load plants and will be forced to rely on other, more expensive, sources of power. Both of these types of forecasting errors may result in a significant price penalty to the rate payers or a significant profit penalty to the utility.
>
> Q. Can improved forecasting methods predict the future demand for electricity with absolute certainty?
>
> A. No, the development of more sophisticated forecasting methods will not eliminate the underlying uncertainty that accompanies the forecast of the future demand for electric power. However, the key question which a utility and a utility regulatory commission must ask is not whether demand will grow at exactly one rate or another. The important question is what steps should the utility take to protect itself and its rate payers against the unavoidable risk of forecasting errors while minimizing the cost to the utility and its rate payers of providing this protection [1].

The Simulation Model

The System Dynamics model used in Case 1454 is an early version of the EPPAM (Electric utility Policy and Planning Analysis Model) sequence of

models. Full technical documentation of the EPPAM model was made available to the parties in Case 1454 through a technical report of the Los Alamos Scientific Laboratory prepared for the Environmental Protection Agency and the Department of Energy [2]. The participants in the case also had a short paper that described the application of EPPAM to study the capacity expansion problems of a hypothetical, investor-owned electric utility company [3]. This paper showed the planning advantages that small coal plants offer (relative to large coal plants) because of their shorter construction lead time.

EPPAM is a relatively simple System Dynamics model designed to keep track of the following aspects of the electric utility industry:

- growth in demand for electricity and possible change in the shape of the load duration curve;
- operation of coal and turbine plants to satisfy the demand for power;
- expansion and retirement of coal and turbine plants based on internally generated forecasts of the growth in demand;
- accounting of capital and operating costs and price regulation following the practices of the state regulatory commissions; and
- the financing of construction programs through use of operating income, depreciation expense, and external funding.

As with most System Dynamics models, the key assumptions are those that govern the rates. In EPPAM, two important rates are the rate of capacity initiation for new coal plants and new turbine plants. Modified DYNAMO flow diagrams showing the set of assumptions governing these rates are given in Figs. 2 and 3.

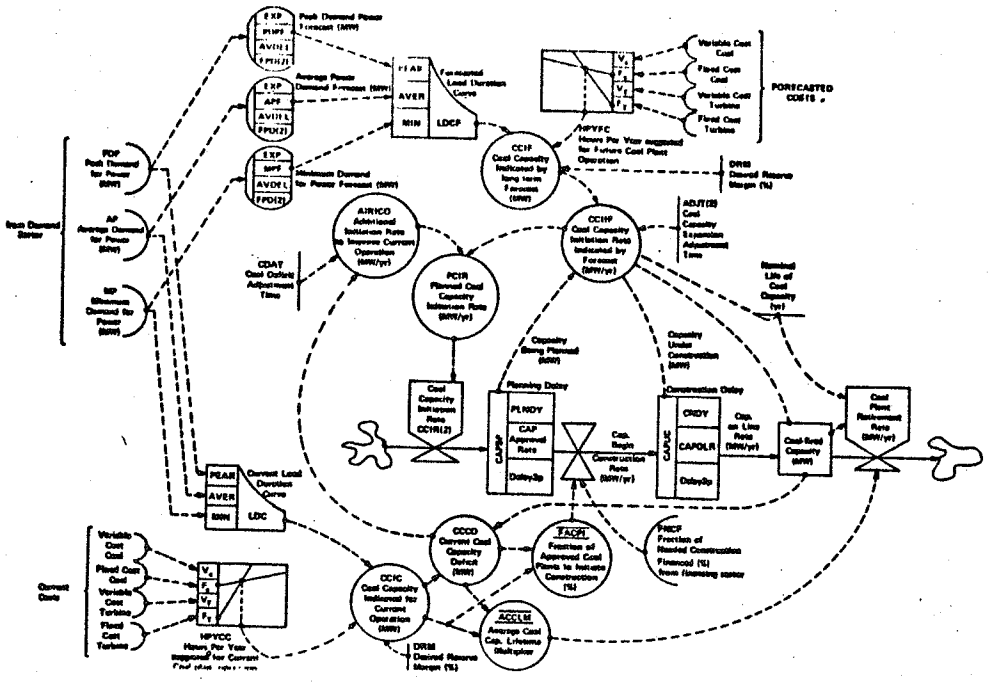


Fig. 2. Modified DYNAMO flow diagram showing coal capacity initiation rate.

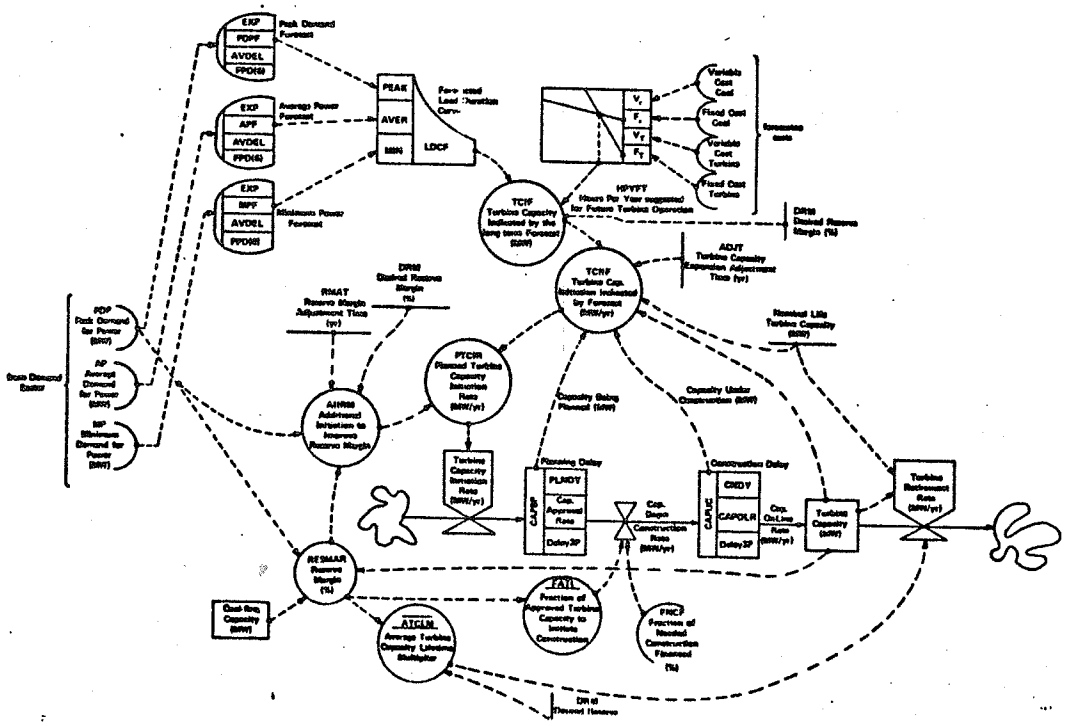


Fig. 3. Modified DYNAMO flow diagram showing turbine capacity initiation rate.

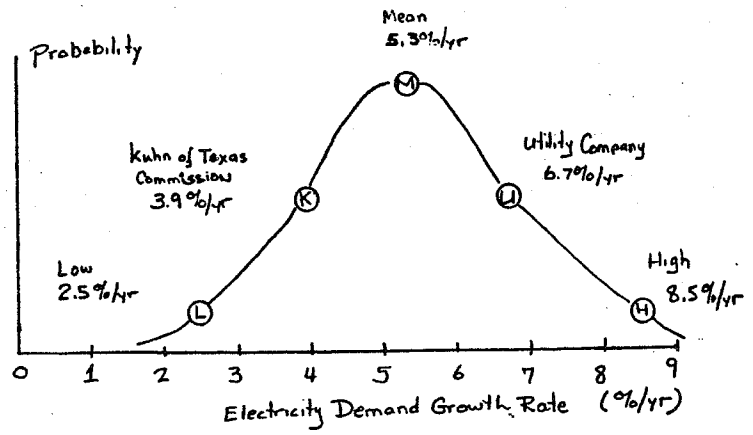


Fig. 4. Assumed probability distribution for the electricity demand growth rate.

Simulation Analysis

The principal exogeneous input required in using the EPPAM model is the indicated growth in electricity demand. In this case, the "low," "mean," and "high" forecasts growth rates noted in Fig. 4 were used to exercise the model. The probability distribution in Fig. 4 was constructed by assuming that the company's forecast of 6.7%/yr and the Texas commission's forecast of 3.9%/yr were equally likely and by assuming a wide range of uncertainty. The "low" and "high" values were purposely used to emphasize the large uncertainty inherent in the demand forecasts.

EPPAM was initialized with the same total capacity, capacity under construction, and load duration curve as the El Paso Electric Company and was used to calculate the average price of electricity that would be charged

under the alternative capacity expansion plans shown in Fig. 1. The results of these model calculations are shown in Fig. 5 for mean demand growth, in Fig. 6 for low demand growth, and in Fig. 7 for high demand growth.

The EPPAM calculations summarized in Figs. 5, 6, and 7 were used to argue that rate payers would benefit from a sale of the company share of the second and third units of the Palo Verde station. The rate benefits were shown to be significant under the most likely demand forecast (Fig. 5) and substantial under the low demand forecast (Fig. 6). Furthermore, the model calculations showed that the sale of units 2 and 3 would not penalize rate payers even under the unusually high demand growth rate assumed in Fig. 7.

Company Criticisms and Counter Analysis

The company's criticism of the EPPAM calculations was based primarily on the inclusion of only coal and turbine plants in the model. El Paso Electric Company, on the other hand, has a combination of gas-fired steam plants, coal-fired steam, and peaking plants in operation as well as the Palo Verde nuclear units under construction. The company argued that the large differences between the fuel costs of the Palo Verde units under construction and the gas-fired units in operation could not be adequately represented by a simulation model whose major source of electric power was coal-fired power plants.

To emphasize the importance of treating natural gas, coal, and nuclear plants separately, the company presented its own model-based analysis in surrebuttal testimony. The company's director of Energy and Environmental Affairs presented economic analysis of the company revenue requirements using a production costs computer model (PROMOD) to calculate the fuel costs to operate a system comprised of different amounts of gas-fired, coal-fired, and nuclear capacity. The company calculations showed

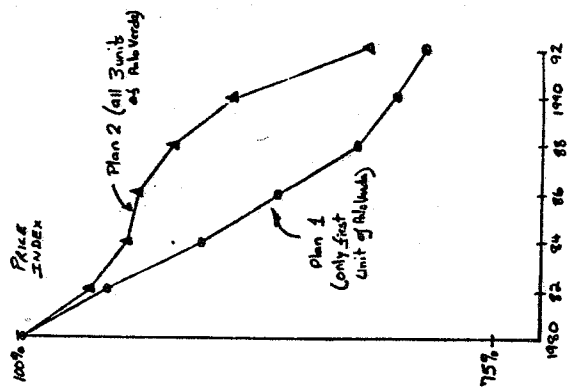


Fig. 6. EPPAM calculation of the price index for Plans 1 and 2 under the "low" demand growth of 2.5%/year.

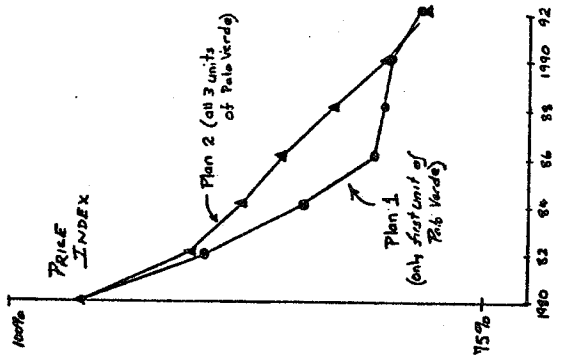


Fig. 5. EPPAM calculation of the price index for Plans 1 and 2 under the "mean" demand 5.3%/year.

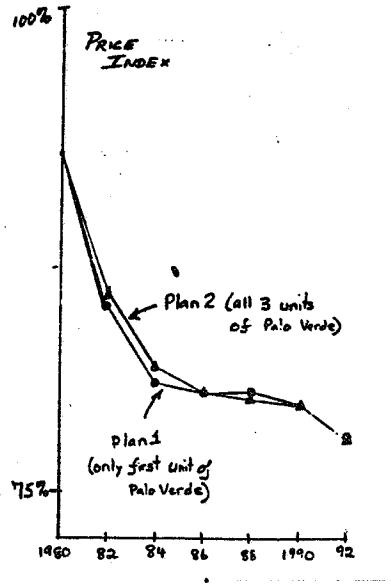


Fig. 7. EPPAM calculation of the price index for Plans 1 and 2 under the "high" demand growth of 8.5%/year.

that total revenue requirements in the year 1986 would increase by $13.5 million if they were to sell their share of the second and third units of the Palo Verde station. This increase arose from calculations showing fuel system production costs increasing by about $93.6 million with the Palo Verde sale and a system capital costs reduction of $80.1 million.

Surrebutal Analysis

The $13.5 million advantage shown in the company rebuttal testimony is reported in Fig. 8 alongside of the results of nine sensitivity tests of the company revenue requirements calculations. In the four revenue requirements labeled as Test 1, for example, the company assumption on the annual increase in the price of natural gas was altered and the effect on the overall revenue requirement determined. In Test 2, the availability factors for the Palo Verde units during their first three years of operation were lowered. Test 3 involved an increase in the construction cost of Palo Verde while Test 4 increased the fixed charge rate used to convert total construction cost into an annual increase in the company's revenue requirements. Figure 8 shows that all nine sensitivity tests showed a reversal of the company findings. Making any one of the nine changes in

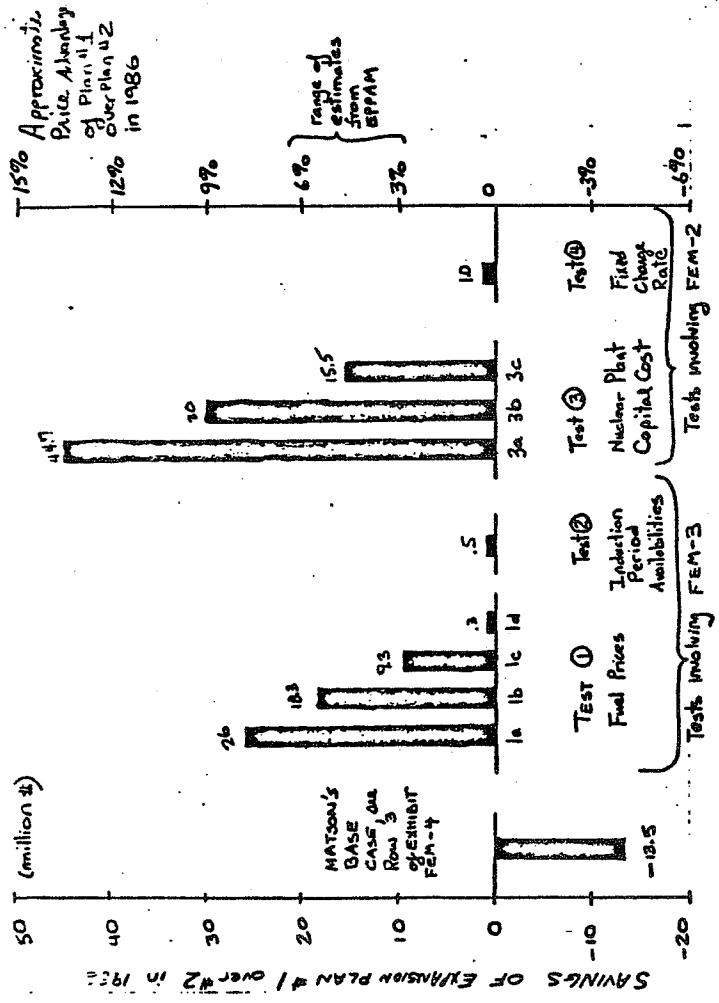


Fig. 8. Results of sensitivity tests of economic calculations performed by Frederic E. Mattson.

assumptions would lead to the conclusion that rate payers would be better off with the sale of the company share of the second and third units of the Palo Verde station.

Commission Decision

Perhaps the best way to wrap up this short description of the analysis and counter analysis in Case 1454 is to give the commission decision on the company request to count construction work in progress in the company rate base:

> After analyzing the vast amount of testimony regarding El Paso's continued participation in the Palo Verde venture, we believe that serious questions have been raised concerning the prudence of El Paso's reliance upon the Palo Verde project as the best means available to serve its customers in the decade of the 1980s. However, we are unwilling to support or encourage the Company's continued participation in the ambitious Palo Verde project at customer expense without an exhaustive review of the costs/benefits of the programs ... In short, El Paso's construction program and means of financing it needs a thorough review [4].

PARTICIPANTS AND SCHEDULE

Participants

The most important participants in Case 1454 were the three commissioners who rendered a decision at the conclusion of the hearings. In New Mexico, the commissioners are appointed by the Governor and are assisted by the commission counsel. In these hearings, it was not possible for all three commissioners to remain in attendance. Often, only one commissioner

was present (at least one commissioner must be present to rule on objections). The commissioners in New Mexico came to the commission with a background in business and regulatory affairs [5].

The El Paso Electric Company was represented by three to four lawyers, a half dozen witnesses employed by the company, and one outside witness from a major university. The Attorney General's contingent consisted of a single lawyer, a part-time consultant, and three witnesses. The list of participants also included a number of intervening groups, usually represented by a single attorney. These included a housing developer from southern New Mexico, a lawyer representing a large military base, and an official from one of the larger towns in southern New Mexico. In some cases, the intervenors took no position in the case; and when they did, they seemed to play a relatively minor role in the hearings. An important exception, however, was a consumer group that intervened to oppose the company's bid to count CWIP in the rate base. Although the consumer group did not bring any separate witnesses before the commission, the group's lawyer was an active participant in questioning witnesses speaking on behalf of the company or the Attorney General.

Next to the commissioners, the lead lawyers for the two principal groups are the key individuals in the hearings. The lead lawyers for the company and for the Attorney General were responsible for putting together the collection of expert testimony to support their positions, for preparing and executing cross examination of witnesses speaking for the opposite side, and for preparing the briefs at the conclusion of the hearings. The lead lawyers remained in attendance throughout the hearings while many of the expert witnesses were only aware of the small segment of the hearings in which they participated directly.

Schedule

To one accustomed to the pace of research in a university and in a national laboratory, the rapid pace of events in Case 1454 was perhaps the most unusual feature. Figure 9 shows the sequence and timing of events in the case. This chronological diagram begins with the issuance of the Palo Verde construction permit in 1973 and the opening of the case in February, 1979. Cross examination of witnesses before the commission ended on May 2, 1979. Nine days later, the company announced a major cost overrun at the Palo Verde construction site and a one-year delay in the scheduled completion date for the first of the three units. Briefs were filed at the end of May, and the commission issued its "Findings of Fact" in June, 1979.

During the months of February and March, the EPPAM model was adapted to represent the El Paso Electric Company. Simulation results were obtained for two expansion plans--one involving all 600 MW of the Palo Verde station, the other including only 200 MW from the first unit of Palo Verde. The

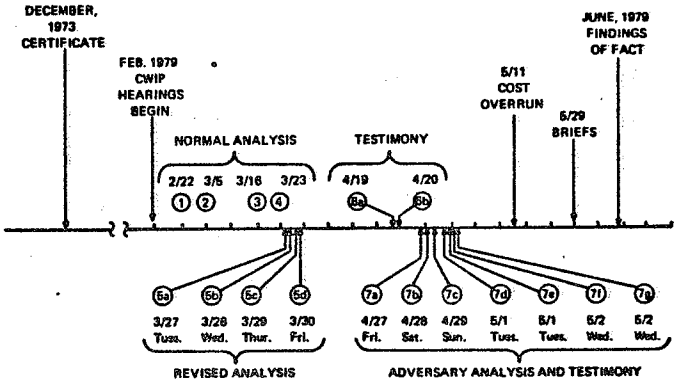


Fig. 9. Schedule of events in Case 1454.

feedback loops leading to an endogenous calculation of any further base load capacity initiations were removed in "the interest of simplicity." That is, the link between the internally calculated "Planned Coal Capacity Initiation Rate" in Fig. 2 was eliminated so that the model would reveal the consequences of following an exogenously specified capacity expansion plan. This line of analysis (called "normal analysis" in Fig. 9) led to shortages of generating capacity under the high demand growth scenario.

By March 27 (Step 5a in Fig. 9) it was decided that the shortages of generating capacity projected under high demand growth was problematical because other Attorney General witnesses were unable to prepare convincing testimony that purchased power would be available from neighboring utilities. Consequently, the link between the Planned Coal Capacity Initiation Rate and the rate in Fig. 2 was returned and the model was allowed to endogenously determine additional capacity initiations required after 1982. Simulation results from this "revised analysis" (summarized in Figs. 5, 6, and 7) were reported to the Attorney General on the 28th of March and submitted in direct testimony on the 30th of March. With the key feedback loops returned to the model, the simulation results showed no problems with capacity shortages under all the demand growth scenarios tested.

The model-based results were presented to the commission on the 19th and 20th of April. On the 19th, cross examination by the consumer group lawyer occurred in a systematic fashion designed to summarize the key findings for those commissioners who may not have had time to study the testimony. The opportunity to review and illuminate the model-based findings occured in this case because the consumer group and the Attorney General both opposed the company request for CWIP in the rate base. On the 20th of April, the pattern of cross examination turned from a systematic summary designed to

illuminate the key findings to a highly critical attack designed to discredit them. The purpose of the company cross examination was to weaken the credibility of the model-based analysis in the eyes of the commission.*

The company attempt to discredit the modeling results shown in Figs. 5, 6, and 7 did not stop with the cross examination on the 20th of April, however. By the 27th of April, rebuttal testimony by three witnesses was filed before the commission. This filing began the portion of the hearings noted as "Adversary analysis and testimony" in Fig. 9. This portion of the analysis and counter analysis proceded quite quickly. Company calculations were found to be highly sensitive to changes in parameter input assumptions on the 28th of April; cross examination to reveal the sensitivity of the company revenue requirements calculations was planned on the 29th; cross examination of company witnesses by the Attorney General's office occurred on the 1st of May (morning and afternoon); surrebuttal testimony showing the results of the sensitivity tests (Fig. 8) was presented to the commission and the company at the end of business on the 1st of May; surrebuttal testimony was presented to the commission in a systematic fashion under cross examination by the consumer group on the 2nd of May; and the company's limited cross examination of the surrebutal analysis was completed on the 2nd of May.

---

*A striking aspect of the lengthy cross examination (to one accustomed to more academic research) is the ratio of the time in presentation versus the time available for preparation. In Case 1454, the model-based analysis was prepared in the months of February and March while the cross examination lasted for 1-1/2 days. In academic research, one may be allowed one to two years for model development and analysis, but only find time for a one-hour presentation to the individuals who will judge the model's usefulness.

The fast pace of events shown in Fig. 9 is one of the more important environmental factors in determining the suitability of system dynamics models under adversary conditions. The features that make system dynamics useful in university research (where a good number of system dynamics practitioners are employed) may be irrelevant under the accelerated pace of adversary hearings. This and other conclusions are discussed in the final part of this paper.

SUITABILITY OF SYSTEM DYNAMICS

I begin the third part of this paper by referring to several strengths of the system dynamics technique and noting whether these strengths proved to be useful under the adversary conditions in Case 1454. Then I turn to certain weaknesses sometimes attributed to the system dynamics approach and note whether such weaknesses were relevant. I conclude with a brief discussion of the relevance of certain "confidence tests" said to be important in evaluating the usefulness of system dynamics models.

Advantages

The key advantage of the system dynamics approach is the ease with which feedback loops can be represented and analyzed. This advantage proved to be crucial in the analysis conducted in Case 1454. The key feedback loops governing the rate of initiation of new coal capacity (see Fig. 2) were found to be crucial when the results of the "normal analysis" conducted in February and March (see Fig. 9) showed shortages of generating capacity

under rapid growth (and exogenously specified initiation rates). Returning the feedback loops to the model and repeating the analysis ("revised analysis" in Fig. 9) eliminated the problem of capacity shortages.

The feedback loop structure of the electric utility simulation model was not only useful in the "revised anlaysis" stage, it was also helpful in the "adversary analysis and testimony" stage of the hearings. Company witnesses giving rebuttal testimony aimed at discrediting the simulation analysis seemed unaware of the likely pattern of behavior of the capacity initiation rates calculated endogenously in the model. Their criticisms of the model behavior in rebuttal testimony were often inaccurate, and the inaccuracies seemed to arise from a lack of understanding of the difference between an endogenously calculated capacity expansion plan and an exogenously specified plan typical of "open system" models.

System dynamics models, when limited to a manageable size, offer an important advantage in the ease with which structural changes and parameter changes may be introduced. This advantage also proved to be important in Case 1454, especially during the "revised analysis" phase, when a large number of new simulations experiments were performed on the 28th of March (Step 5b in Fig. 9).

In my opinion, the second most important strength of the system dynamics approach is the array of descriptive aids that make thorough documentation possible. Causal loop diagrams, DYNAMO flow diagrams, documented listings, and DYNAMO listings allow the system dynamics practitioner to prepare several "layers" of documentation. This advantage is crucial to the success of system dynamics in the academic world where progress is achieved by the reproducibility of simulation experiments by different analysts in different research institutes. Thorough documentation is not, however, a

useful feature under adversary proceedings. Indeed, it appeared from the events in Case 1454 that thorough model documentation gives the opposing participants the opportunity to "come-up-to-speed" rapidly and develop the most effective strategy for discrediting the model in cross examination. Moreover, the use of PROMOD in Case 1454 showed that participants could deliver testimony based on the results of models that were completely undocumented due to their proprietary nature. The Attorney General objected to the use of the proprietary PROMOD model in Case 1454, based in part on the lack of documentation:

> Q. Please summarize your response to Dr. Mattson's rebuttal testimony.
>
> A. Mr. Mattson's rebuttal testimony invites a more informative exchange of ideas than Dr. Baughman's because he attempts to describe the purported benefits of investment in Units 2 and 3 of Palo Verde in quantitative terms. Unfortunately, however, he has used a proprietary computer code known as PROMOD. The proprietary nature of PROMOD does not allow Mr. Mattson's calculation to be examined in detail. The use of computer models without explanation of the inner workings of the model is unscientific and should not be allowed in a proceeding such as this.
>
> Q. In what sense is the use of PROMOD unscientific?
>
> A. A key feature of the scientific method is that results advanced by one scientist should be reproducible by other scientists. This principle is most familiar to those engaged in work in the sciences of chemistry and physics. In these disciplines, results of a chemical or physical experiment are not considered to be "scientific" unless another chemist or physicist can reproduce the same experiment in his or her own laboratory. Without reproducibility, the sciences of chemistry and physics would not advance. Indeed, this principle is so well established that one publisher publishes a "Journal of Irreproducible Results" as a parody on the scientific method. Although more familiar to the physical sciences, the principle of reproducibility is just as important in the economic sciences.
>
> The economic calculations based on PROMOD and presented before this Commission cannot be independently reproduced by either the Commission staff, by intervenors, or, for that matter, by analysts testifying on behalf of the El

188

> Paso Electric Company. None of these potential users have access to the computer equations of the PROMOD model because of restrictions placed on its use by Energy Management Associates of Atlanta, Georgia [6].

Despite the objections to the company use of PROMOD, the commission ruled that the company calculation could be entered on the record.

Disadvantages

Now, what about the weaknesses sometimes attributed to the system dynamics approach? Perhaps the most frequently discussed weakness within the modeling community is the "informal" fashion with which many parameter estimates are obtained. Modelers accustomed to the formal estimation procedures used in econometrics have criticized the system dynamics procedure as lacking an empirical base [7]. From the events in Case 1454, I would conclude that this criticism is not likely to be important in adversary proceedings before state public utility commissions. Very seldom do the commissioners and their key staff have a background in formal modeling and statistical methods that would make them receptive to the criticisms sometimes voiced by econometricians. Furthermore, the commissioners have sat through numerous hearings in which econometricians battle one another trying to discredit each other's electricity demand forecast. This constant clashing of econometricians has contributed to a healthy skepticism in the commissioners toward the "science" of econometrics.

Another criticism of system dynamics, sometimes voiced by those modelers more accustomed to optimization modeling, is that the model does not employ a formalized objective function. This type of criticism was not relevant in Case 1454 because the interpretation of the simulation results in Fig. 5, 6, and 7 was not difficult. However, in other cases where simulation results have been presented before state commissions with short-term,

long-term tradeoffs, for example, simulation models have been heavily criticized for not including a formal objective function.*

Another weakness of the system dynamics technique is the reliance on continuous approximations to discrete changes. Although Forrester warns the beginner not "to be carried away by his knowledge of the discreteness of various decisions and actions" [10], commissioners may wonder how a major discrete event (like the sale of a large amount of common stock) could be adequately approximated by a continuous simulation model. This type of questioning did not arise in Case 1454, but I suspect it will come up in future hearings if system dynamics models are used to represent individual companies.

Confidence Testing

Forrester and Senge [11] present "confidence-building tests" that one can use to improve the usefulness of a system dynamics model. Based on the events in Case 1454, I would label 7 of these tests as irrelevant because of the fast pace of the proceedings.

- The "extreme conditions" test, the "extreme policy" test, and the "behavior anomaly" test are helpful to establish self confidence by the model developer, but they are not likely to be relevant tests that one could cite in defending model "validity" under cross examination. Furthermore, I do not think it is likely that opposing groups will attempt to discredit a model because it is not capable of

*For example, the simulation analysis of the Pacific Gas and Electric capital expansion plan by the Environmental Defense Fund (8) was repeatedly criticized by the PG&E consultants for not including a formal objective function (9) in testimony before the California Public Utilities Commission.

passing one of these tests. Such testing does not appear to be possible given the pace of adversary hearings.

- The "family member" test is a very appealing test for analysts interested in generic structures and their ability to explain problematical behavior patterns found in many different systems. It is not likely, however, that participants in adversary hearings before an electric utility commission would find this test convincing. Indeed, some participants might feel that a model was "invalid" if it relied heavily on theories taken from other members of the "family."
- The "dimensional consistency" test is another test that the model builder should perform to satisfy himself that the model has been correctly structured, but it is not likely that participants in adversary hearings will find reference to this test convincing. A possible exception, however, would be a commissioner with a background in engineering since engineers are more accustomed to checking their calculations for dimensional consistency.
- The "surprise behavior" (counter-intuitive behavior?) test is another test that participants in adversary proceedings are not likely to appreciate. Such a test is more likely to help the model builder perform his research and analysis with confidence than to help others gain confidence in the "validity" of the model.
- "Other tests," by which Forrester and Senge [Ref. 11, p. 223] mean the array of statistical tests employed in econometric modeling, are likely to be unimportant in adversary proceedings. Econometricians familiar with these tests are more likely to question the ability of the model to reproduce historical behavior--a test mentioned below.

Other tests discussed by Forrester and Senge may be valuable in defending model "validity" under adversary proceedings. These include:

- The "behavior reproduction" test was not specifically mentioned in Case 1454, but it seems that this question could easily be raised by participants attempting to discredit a model. A reason for not inquiring about the test, however, is that the model developer may have already subjected the model to such a test and be in a position to speak positively about the results before the commission.
- The "boundary adequacy" test is another test that could well be important because participants in adversary proceedings can easily learn what has been omitted from a model. Thus, questions about the adequacy of the model boundary come quickly to mind. In Case 1454, for example, Federal prohibitions on the use of combustion turbines were outside the model boundary. To check the importance of this omission, exogenous, time-dependent table functions were introduced to [illegible] that extra turbines would be on line in time to have each individual turbine operate in compliance with the Federal rules. The model was then used to calculate the incremental increase in the price of electricity arising from the need to comply with Federal rules. The fact that this particular test was performed in an exogenous fashion did not appear important to the commission--what was important was that the comparison of electricity prices in Figs. 5, 6, and 7 did not change with the increased number of turbines.
- The "parameter-verification" test is another test that could well be important, especially if all the model parameters are documented in a highly visible fashion. Opposing participants in adversary proceedings could scan the list of parameter values looking for unusual estimates to be discussed in cross examination.
- And finally, the "behavior sensitivity" test is an important test to perform in the midst of adversary analysis, especially if one can anticipate objections to certain parameter estimates used in the model. Indeed, one of the most useful functions of a system dynamics model (or other mathematical models) is to show whether particular parameters really need to be specified with much precision. From the events in Case 1454, I conclude that sensitivity testing is one of the more important of the many tests discussed by Forrester and Senge. It is particularly helpful in answering questions under cross examination, for example, to have performed the proper sensitivity tests in advance.

I do not wish to state that only four of the many confidence tests discussed by Forrester and Senge are important to system dynamics applications under adversary proceedings. All of the tests serve a valuable role for the model developer by increasing his confidence in the analysis. However, not all of them are likely to contribute directly to a defense of model validity or usefulness under questioning by opposing participants in adversary hearings. Although the list presented by Forrester and Senge is one of the longer lists in the literature on model validation, I would add another test that appears worthwhile under adversary proceedings. This might be called the "previously-published behavior reproduction" test, for it involves a comparison of the pattern of behavior presented in the current hearing with previous projections given in articles or reports available to opposing participants. It appears that a standard means of discrediting expert testimony is to search through the witness' publications looking for projections or conclusions that conflict with the projections and conclusions given in the current hearing. To counter this practice, the modeler

should review previous projections checking for possible conflicts with the current testimony. During the course of the review, one should also check for conflicts with model projections over time intervals for which time series data is now available.

SUMMARY

This paper recalls the analysis, counter analysis, participants, and schedule of Case 1454 with a focus on the use of a system dynamics model of the electric utility industry. The principal lesson to be learned from Case 1454 is that system dynamics can contribute to informed decision making under adversary proceedings despite the rapid pace and adversary nature of such proceedings. Key advantages of the system dynamics approach are the ease of representing feedback loops and the ease in making structural and parameter changes. The thorough documentation that often accompanies system dynamics models constructed in the public sector, however, is likely to serve the opposing participants and decrease the effectiveness of system dynamic model-based testimony under adversary conditions. The paper concludes with a discussion of numerous tests said to be useful in increasing one's confidence in a system dynamics analysis. It is concluded that many of these tests are not likely to contribute directly to the defense of model "validity" under cross examination by opposing participants.

REFERENCES

[1] Direct Testimony by Andrew Ford before the New Mexico Public Service Commission, Case No. 1454, March 30, 1979, p. 3.

[2] Andrew Ford and Irving Yabroff, "Technical Documentation of the Electric Utility Policy and Planning Analysis Model," Los Alamos Scientific Laboratory report LA-7773-MS (June 1979).

[3] Andrew Ford and Irving Yabroff, "Defending Against Uncertainty in the Electric Utility Industry," in Energy Systems and Policy, Vol. 4, Nos. 1 and 2 (Crane Russak, New York, 1980).

[4] "Findings of Fact and Order on Revenue Requirements," New Mexico Public Service Commission, Case No. 1454 (1979), p. 19,20.

[5] National Association of Regulatory Utility Commissioners, "1978 Annual Report on Utility and Carrier Regulation," (National Association of Regulatory Commissions, 1979), p. 700.

[6] Surrebuttal Testimony by Andrew Ford before the New Mexico Public Service Commission, Case No. 1454, March 30, 1979.

[7] A. A. Legasto, Jr. and J. Maciaeriello, "System Dynamics: A Critical Review," in Studies in the Management Sciences, System Dynamics, A. A. Legasto, Jr., J. W. Forrester, and J. M. Lyneis, Editors (North-Holland, 1980).

[8] W. R. Z. Willey, " Alternative Energy Systems for Pacific Gas & Electric Co.: An Economic Analysis," the Environmental Defense Fund (1978).

[9] H. Pifer, W. Hieronymus, J. Ristuccia, and M. Schnitzer, "An Independent Evaluation of EDF's Electric Utility Financial Simulation Model," Joint Hearing of OII-26 and OII-42 before the California Public Utilities Commission (1978).

[10] Jay W. Forrester, Industrial Dynamics (MIT Press, Cambridge, Massachusetts, 1961).

[11] Jay W. Forrester and Peter M. Senge, "Tests for Building Confidence in System Dynamics Models," in TIMS Studies in the Management Sciences, Vol. 14, System Dynamics, A. A. Legasto, Jr., J. W. Forrester, and J. M. Lyneis, Editors (North-Holland Press, 1980).