BNL 26138

CONF-790158--1

MASTER

VALIDATION ISSUES: A VIEW FROM THE TRENCHES

JANUARY, 1979

PRESENTED AT DOE/NBS WORKSHOP ON VALIDATION & ASSESSMENT OF ENERGY MODELS

W. MARCUSE
D. PILATI
BROOKHAVEN NATIONAL LABORATORY

T. SPARROW
PURDUE UNIVERSITY

DISCLAIMER

MASTER

VALIDATION ISSUES: A VIEW FROM THE TRENCHES*

By

W. Marcuse
D. Pilati

Economic Analysis Division
National Center for the Analysis of Energy Systems
Brookhaven National Laboratory
Upton, New York 11973

T. Sparrow

School of Industrial Engineering and
Department of Economics
Purdue University
West Lafayette, Indiana

Presented at DOE/NBS Workshop on
Validation & Assessment of Energy Models,
January 10-11, 1979, NBS Headquarters,
Gaithersburg, Maryland

*Work supported by the U.S. Department of Energy
under Contract No. EY-76-C-02-0016.

VALIDATION ISSUES--A VIEW FROM THE TRENCHES*

I. Introduction

A great deal of attention has been directed towards model evaluation and assessment. A bibliography compiled by Saul Gass lists 37 articles and monographs and 14 books and reports devoted to model evaluation or assessment. (Gass, undated) Most of these, in dealing with verification and validation, discuss means and mechanisms by which "outside" parties can perform peer review to provide verification (model behavioral response is as intended and publicized) and establish the validity (model produces results one would expect, e.g., in the case of most models, it will recreate history) of models. (Gass, 1977) Little attention is paid to activities performed by the user modeling team itself to improve the ability of the model to provide information useful in the decision making process, and to provide confidence that the information is meaningful.

This paper presents a number of case histories describing our experience with this type of model improvement activity which we have called internal validation. Our experiences are illuminating since they were learned in the context of formulating, developing, and exercising a specific set of process models. This experience has convinced us that internal validation schemes (our definition) should be incorporated in the project description and that they be used in part to answer questions of formulation. Having discovered the need to perform explicit internal validation, we recommend that modelers incorporate sufficient funding in their project plans to carry out this function and to fully document it. In general, this will be an unwelcome addition to sponsors already unhappy with the size of their modeling budget.

II. The Decision Process

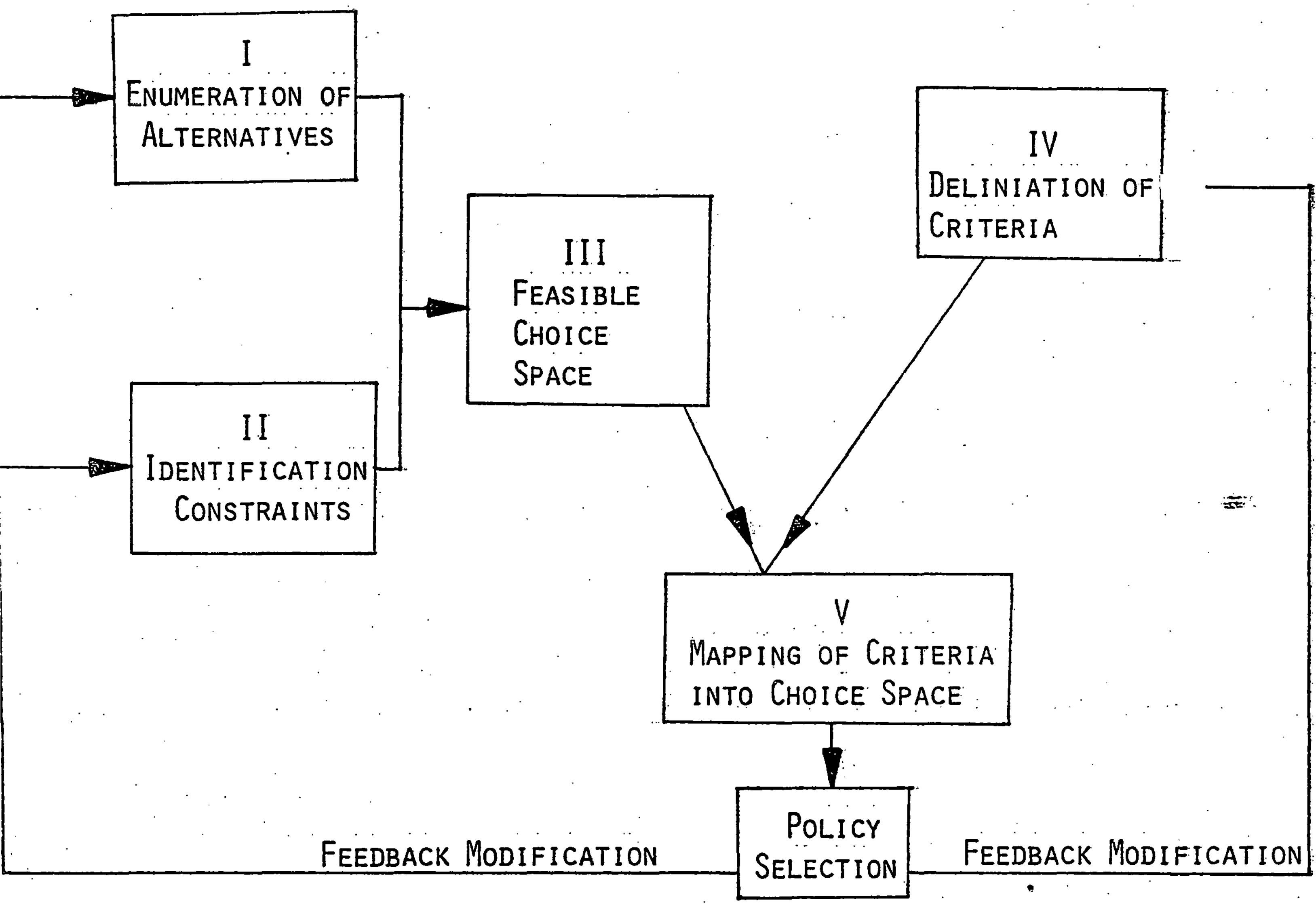
Increasingly, we turn to government to intercede in areas where economic equilibrium is subject to market failures; where externalities previously ignored were now considered socially undersirable, or where political goals have to be satisfied. These activities require the manipulation of enormous data bases. This has prompted an increased acceptance of information provided by quantitative models capable of such manipulation by the actors in the decision process and an increased demand for such tools. It is not surprising that model builders and users have evidenced increased concern with regard to the quality of their products.

Figure 1 indicates where such models can fit into the decision process. Decision makers are faced with a wide range of policies and actions (Box 1). They also are acutely aware of the political and institutional limitations

*Work supported by the U.S. Department of Energy under Contract No. EY-76-C-02-0016.

FIGURE 1

An Idealized Decision Process



MODELS GOOD AT III, V: DECISION MAKERS MUST PROVIDE I, II, IV; THEN CLEAR THAT MODELS ARE ADJUNCT TO DECISION PROCESS.

on their freedom to pursue these alternatives (Box II). Physical and economic constraints are also recognized although their perception may be dimmer. The interaction of the alternatives with the identified constraints identifies a "feasible choice space" (Box III). The decision maker must also specify the value system weights that will be used to rank-order the outcomes of alternative policy decisions (Box IV). This is a very difficult and painful task and is often accomplished poorly within the decision structure. Mapping the criteria the choice space yields an ordering of the outcomes (Box V). Conceptually, this process results in the identification of the preferred policy choice. Models are generally recognized as performing the tasks in Boxes III and quite well; however, the decision makers must provide the bulk of the information required from Boxes I, II, and IV. Models influence these activities only by the feedback loops shown in the figure. Unfortunately, the information provided by the models will never be perfect but hopefully can be improved. It is the process of improvement that we shall call validation. The purpose of models we are examining is to lead to improved decisions and the purpose of model validation is to lead to improved information flow into the decision process. Model improvement occurs not only as the model meets criteria or standards set by a professional modeling community, but as the modeling process better suits the needs of the decision process, i.e., users should play a key role in validation. This does not mean that professionally derived criteria should be ignored but rather that the professional criteria should be developed so that validation is defined within the decision context. Hence, it may differ from topic to topic, model to model, and even from decision maker to decision maker within the same topical area using the same model.

If the object of model validation is to improve the model, then how does one define improvement? One definition might define improvement as model modification which leads to better decisions. Note that this definition requires the term "model" to be interpreted as a complete process including formulation, development, application, documentation, interpretation, and review. In the absence of a meaningful operational measure of "better" decisions an alternative (but still qualitative assessment) of validity might be whether the actors in the decision process feel comfortable with the modeling process and its results.

Two cardinal rules that should be adhered to in policy modeling activities are:

1. Users (decision makers or their staffs) should participate in the entire modeling process including frequent review during the development phase since reformulation is a continuing activity.

2. The choice of key variables and the model structure must be consistent with the key policy questions faced by the decision maker. The assumptions, strengths, and limitations of models and their results must be clearly understood if models are to be used effectively in the decision process. (Greenberger, 1976)

To some extent, aking decision makers and their staffs to participate in modeling activities is unrealistic. However, unless considerable interaction takes place, especially with respect to model formulation and the interpretation of outputs, not only are models likely to be ignored, but worse, the product may be used improperly. Introducing a process which insures that the model behaves as intended and that there is agreement between the behavior of the model and the real world will do nothing to insure that the model is designed to answer key user questions or that the model assumptions and limitations are fully acknowledged by the user in the interpretation of the model outcomes.

Finally, it is important to recognize that models which might stand up quite well in comparing the difference in outcomes under alternative policies might fare quite poorly as simulators of history whereas models that simulated past history well might mask or accentuate the effects of alternative policies. (Marcuse, 1979) We must make sure to avoid this trap when attempting to use the ability of a model to reproduce history as a validation criterion; more will be said about this problem later in the paper.

III. The Modeling Process

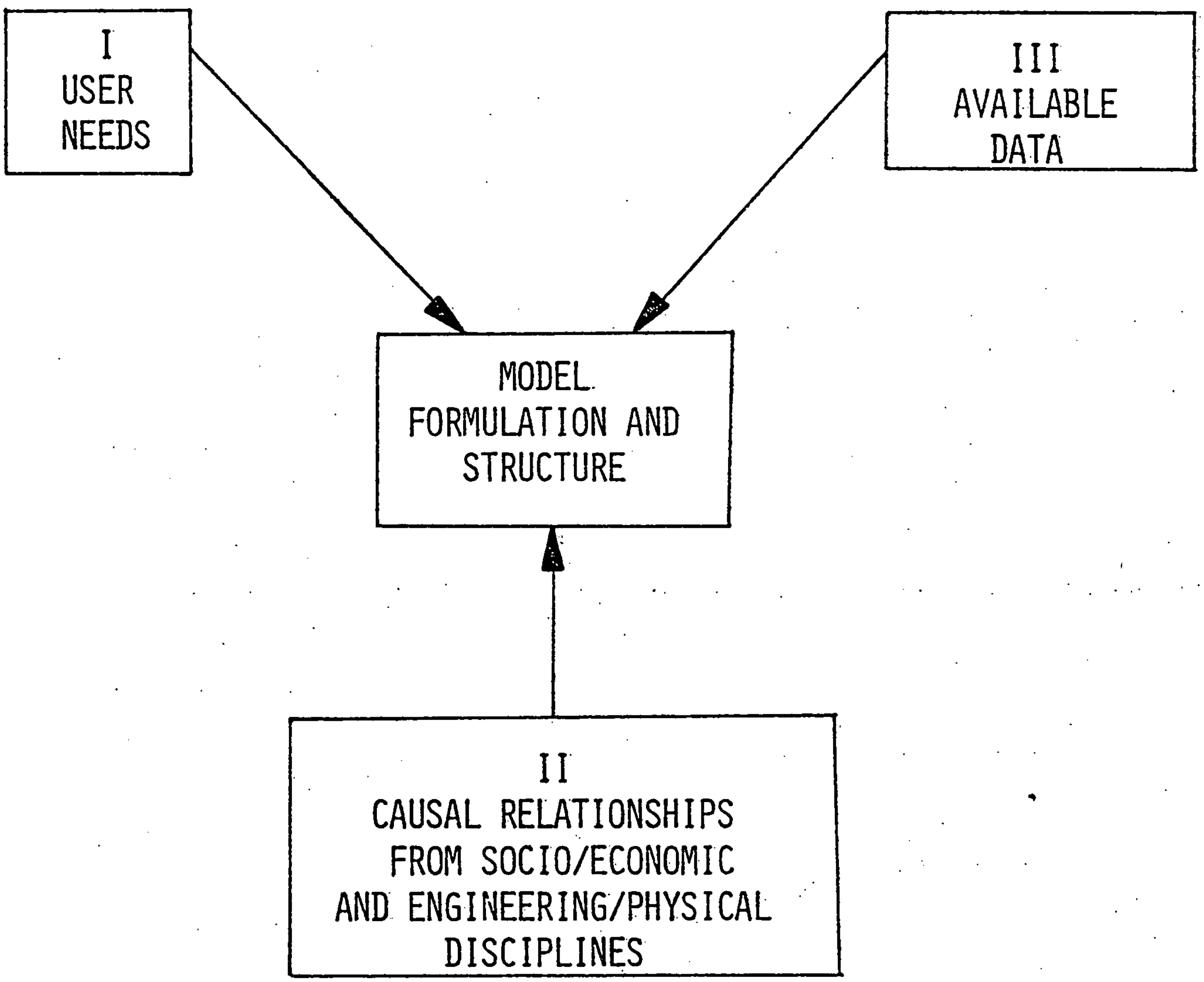
The modeling process consists of model development, application, and internal validation and the feedbacks associated with these activities. These subprocesses are inseparably intermeshed. The nature and content of the development and application subprocesses are clear. The character of the validation subprocess is obscure, often unrecognized, and seldom documented. Our experience indicates that it is critically important, and that not only should internal validation be explicitly incorporated as a task in a modeling effort but also that modeling efforts should specifically require documentation of internal validation results.

Figure 2 presents a functional breakdown of policy modeling activities. The modeler occupies the central box on the diagram. He develops, exercises, and improves a model that combines data (III) and causal relationships (II) to provide answers to key questions posed by the user (I). Because decision models by their nature span several disciplines (e.g., economic, engineering, environmental), the modeling team should be multi-disciplined so that causal relationships from the various disciplines are correctly specified and data are properly interpreted.

The link between the modeler and the user calls for the modeler to ascertain jointly with the user what information the user needs in response to what questions the user might ask. In passing, it might be noted that some have attributed the demise of RANN in NSF to it's failure to properly recognize the need for close co-operation between users and modelers. The modeling effort must be closely integrated with those involved with the policy planning process in order to assure pertinent and useful information. (NAS, 1976).

FIGURE 2

THE MODELING PROCESS: MODEL STRUCTURE A COMPROMISE--
BRIDGES GAP BETWEEN DATA AND NEEDS



The linkage between the modeler and the causal relationship box represents the incorporation of the results, laws, or "great truths" about the particular problem accumulated from previous work; such information is usually very discipline-oriented, not problem or needs oriented. Finally, the third linkage between the modeler and available data acts as a key element (and usually the most serious constraint) for the model formulation and structuring activity.

The entire process is interconnected. The selected modeling structure must not only be responsive to the user questions but must also be consistent with the available data and known causal relationships. If data are not available, then a different structural approach must be used. Modelers must be careful not to generate a model structure which nicely answers the questions but cannot be supported by existing data. An internal validation task would call for a report confirming that the data requirements generated by the model structure can be achieved. Another internal validation task is to identify new or additional data that will affect model results or structure.

Table 1 lists a set of issues or questions associated with each aspect of the modeling process. The answers to each must be consistent with all of the others. Certainly changing the information desired by user will generally require structural changes in the model which in turn will require data modification and inclusion of different causal relationships. However, such a change in the structure not only requires modified data but so broadens (or sometimes narrows) the range of questions available to the user. Finally, new data permit structural modification which in turn can permit modifications in use.

In the early stages of any modeling effort, the validation function will tend to be concentrated on data aspects. As data requirements are generated, an assessment has to be made not only of the quantity and quality of the available data but also if its form and definition are consistent with the causal relationships of the model. As one looks at the charter of the Energy Information Administration, these activities seem to be the focus of current interest. (DOE, 1977)

As the model proceeds through the development stage and begins to be applied, validation activities occur as a result of interaction with users and other modelers. These validation activities should be incorporated in project funding.

The remainder of this paper is directed to documenting the process of selecting the model and some examples of unanticipated internal validation exercises encountered in industrial energy policy modeling.

TABLE I

INTERNAL VALIDATION ISSUES FOR MODEL STRUCTURE

USE	Does model treat the "right" questions? Are results usable in the decision process? Are the policy variables of importance easily manipulated by the user?
CASUAL RELATIONSHIPS	Is the model formulation consistent with other studies? Are the assumptions reasonable? Are the contraints realistic? If behavioral characteristics are implicit, are the implications understood? Is the level of disaggregation reasonable?
DATA	Do data exist at the level of disaggregation of the model? Are data available (proprietary)? Are data at the "right" level of detail? Are data of reasonable quality?

IV. Background on Choice of Models

At the inception of the industry conservation modeling activity, the first action was to select the kind of model. This choice was determined by user needs. The Division of Industrial Conservation (INDUS) of ERDA* had responsibility for technology-based RD&D programs directed toward improving energy end-use efficiency in industry.** It was immediately recognized that in addition to modeling technologies one had to have models capable of assessing the impact on industrial energy-using capital investment decisions of various price and non-price policies to properly assess their RD&D programs. The merging of ERDA's technology mission and FEA is (now EIA) policy mission in one single agency made such models all the more desirable, since issues of trading off policy options against R&D options are central to DOE's mission

*ERDA, the Energy Research and Development Agency which was absorbed by the newly formed Department of Energy in October 1977.

**Industry is defined quite broadly and includes all energy use outside the residential, commercial, and transportation sectors.

A choice had to be made between an econometric approach and process approach for the structure of the industrial energy policy models. Given the advantages and disadvantages of each as depicted in Table 2, the process approach was preferred. This does not preclude the use of econometric analysis to support and supplement the process models.

Comparison of Process Optimization and Econometric Approaches

First, the user wished to assess the probable impact of introducing specific process technologies into production facilities. The process approach which requires specific representation for each new and existing technology seemed to have a definite advantage over an approach that would (at best) identify the impact of new technologies as some kind of generalized energy efficiency improvement. Moreover, the impact of specific policies (e.g., tax credits), could be assessed with respect to their effect on each technical alternative. An econometric approach would indicate a generalized response to a policy initiative which could not be easily partitioned among the competing alternatives.

Second, the process approach uses more direct engineering information and less econometrically estimated data. Since initially the model users were all engineers, this had the advantage of characterizing the data input and technical alternatives in terms familiar to personnel in the using organization. However, the process models also permit consideration of the policy options of interest to those trained as economists. Since a basic tenet of the BNL approach to energy-economic process modeling is to marry the two methodologies, the BNL staff was equally comfortable with either type of model.

One need of the user is to identify the market penetration of new technologies over an extended time horizon. He should be able to generate such information under varying tax policies, fuel price projections, product demand projections, technology cost assumptions, alternative technology availability, and levels of technology and specific government support. Once again, the explicit process representation permits examination of both the utilization of existing capacity and the change in the composition of capital stock over time.

The response of an industry to changes in energy prices will be related to the age structure of its capital equipment. By using a vintage capital representation for industry, a process model can largely capture this effect. An econometric model captures the effect of vintage stock that existed in the historical period from which the data were obtained. There is no reason to expect, a priori, that this is the same relative vintage and efficiency as in the current period. Even if the data were cross-sectional, there is no reason to believe that the vintaging across geographical regions is either random or uniform. In fact, there is good reason to believe just the opposite.

TABLE 2

MODEL SELECTION

ECONOMETRIC PREFERRED WHEN:	PROCESS OPTIMIZATION PREFERRED WHEN:
Focus on aggregated relationships	Focus on disaggregated relationships, especially investments in and use of specific technologies
Interest in equilibrium	Interest in path to equilibrium
Data limited and aggregated	Disaggregated data available
Behavioral response is unchanged	Behavioral response changes predictably
Institutional structure is constant	Institutions change predictably

NOTE: The models are in reality complements not substitutes; each is capable of answering different (in general) questions, or can be used in tandem to answer the same question.

Economic-Engineering Interface

The models chosen to analyze industrial energy conservation alternatives primarily utilize engineering data. This is an advantage since existing and "near-in" technologies are characterized by factual process descriptive parameters as opposed to statistical estimates. On the other hand, characterization of "down the road" and "over the horizon" technical alternatives are at best characterized with great uncertainty and at worst ignored. The economic assumptions underlying capital investment and output decisions are minimal and explicit, whereas in econometric models they are hidden.

Data

The unavailability of suitable data often acts as a barrier to the use of process approaches. Sparse sets of highly aggregated data forces one into using statistical techniques. These results are often unsatisfactory because the generalized relationships may mask the detailed adjustments taking place within the system. Even worse, the definitional frame is set by the data and often does not exactly correspond to the area being studied. In contrast, industry process models depend upon highly disaggregated data sets.

Fortunately, much disaggregated data exist; but often in the form of single point estimates. These data were generated, analyzed and improved in an adversary environment in the early 1970's in connection with the introduction of environmental requirements on industry and later by the FEA in setting voluntary industry energy use targets. Since most industrial processes affected by emissions regulations are high energy consumers, both data sets were made to order for the industrial energy process models. As a result, we have a large data base of well-worked data. Data on additional processes and technical changes will require industry cooperation or further government-funded studies.

Although the technical descriptions in the industrial process data base are quite reliable, we have had considerable difficulty with the cost data, particularly capital costs. These difficulties arise from several sources. First, capital costs have risen rapidly and unevenly since studies were made in the early and mid 1970's and utilizing the relative costs of that time period may be quite misleading. Second, the definition of capital costs varies greatly depending upon accounting methods used, treatment of construction costs, treatment of depreciation, and definition of the boundaries of the system that is being costed. Third, it is difficult for a process model to discern between greenfield (new) or roundout (retrofit or plant expansion) investments; each has a different capital cost for a particular price of equipment. This is one of the major data weaknesses in the process models.

V. Internal Validation Case Histories

The case histories described in this section illustrate validation issues that have emerged in the development and application of our steel industry process optimization models. Many of them have not been resolved. It is this process of identifying the issue and taking appropriate action to resolve it, followed by careful documentation, that has been defined as internal validation. Some of the issues described below have not been completely (or satisfactorily) resolved primarily due to a lack of resources. Besides identifying and resolving issues, part of the validation process is to record the unresolved issues and the reasons they remain unresolved.

Case History 1 - How Should We Keep Our Books?

This is an example of a data problem. We found that the capital cost estimates redundant for the dry coking process in steelmaking vary widely. Upon examination, it was clear that capital costs quoted by the vendor were much lower than buyer's estimates of capital cost. (A.D. Little, 1978) This difference is surprising since the process is used extensively by steel producers in the USSR. When the question is asked why has it not been adopted by American industry, the industry says that it is too costly and the equipment vendors claim the costs are no higher than abroad. In fact, vendor price is considerably lower than buyer cost because the buyer includes installation, and set up costs and properly charges these to his capital account. He also incorporates in his investment decision the performance uncertainty associated with new technology. Resolution of this issue is important. It may reflect differences in accounting, cost structure, or risk acceptance between the U.S. and U.S.S.R. Is the basis of the problem institutional or accounting and if so, are there policy options available to redress it? We are still looking into this question.

Case History 2 - Where Do You Draw System Boundaries?

This example is similar to the first one in that the issues concerns data. In this case it is technical fuel use data that is in question. The issue concerns the Btu consumption of a blast furnace. One group asserts that on a Btu for Btu basis coke substitution for hydrocarbons in a blast furnace increases total fuel requirements (Tanenbaum, 1977) whereas another group asserts that such substitution decreases energy consumption. (Woolf, 1974) Three reasons were hypothesized to account for this differential.

1. The substitution effects are a function of where the system boundaries are drawn.

2. Substitution of coke for hydrocarbons leading to less Btu use is supported by pilot plant operations whereas the opposite result has been observed in actual operating environments.

3. There are differences between blast furnaces: some may exhibit increased total energy use with hydrocarbon injection, others vice versa.

While this issue remains unresolved at this time, hypothesis one seems the most likely explanation. Our belief is that one group looked only at the impact on blast furnace Btu use, while the other looked at its impact upon the entire steelmaking process.

Case History 3 - How Do You Assess Data From Advocates?

A major problem associated with modeling new technology, particularly when the idea comes from outside the industry, is the difference in technical and economic feasibility postulated by an enthusiastic inventor as contrasted with conservative managers. Our example of this is the oxygen blown blast furnace and coal gasifier which looks extremely attractive when incorporated in the model with cost and performance parameters supplied by the inventor. (Jordon, undated) Industry claims the process will not work as advertised and will not consider adopting it. In this case the model sponsor accepted the industry position, and we have constrained this process out of model solutions for operational purposes. However, the basic process is being retained as an alternative until we can get further information as to whether the position of industry or the inventor can be accepted. Final resolution will not occur until the inventor can convince someone to build a pilot plant.

Case History 4 - Is Reproducing History Necessary?

In response to accepted validation procedures, the steel model was exercised using product demands, prices, and existing technologies for the post-embargo period 1973-1976 in order to determine how well the model tracked energy consumption during the period. While predicted aggregate energy consumption was within 10% of actual consumption over this period, the behavior of energy intensity (Btu/ton) with respect to capacity utilization in the model was exactly the opposite of that observed during the period (AISI, 1977) Figure 3 illustrates this contradiction.

Actual behavior is explained by the fact that there are large fixed heating requirements in many of the iron and steel making processes which are independent of the level of production over fairly wide ranges of capacity utilization. For example, blast furnaces must be kept hot if any output is anticipated in the near term, because the cost of closing down and then restarting are quite high. This means that reduction in output is accompanied by less than proportional reduction in energy use, which gives rise to the actual behavior illustrated in Figure 3.

Why did the model not reproduce such behavior? The reason is that being a linear programming model, it is mathematically incapable of displaying such scale economies for reasons that need not concern us here. Is this a fatal flaw? Not if one realizes that the model was designed to identify attractive end-using technologies under assumptions of smoothly increasing steel demand without the disruptions caused by business cycles of the sort which produce short-term declines in production. The model was designed for users interested in long run behavior of energy use, not short run response of energy use to business cycles. In this instance, exact reproduction of history is not called for; requiring the model to track history would force a drastic restructuring completely inappropriate for the user's needs. Applying conventional historical validation approaches in this case caused us to use woefully short resources in non-productive ways.

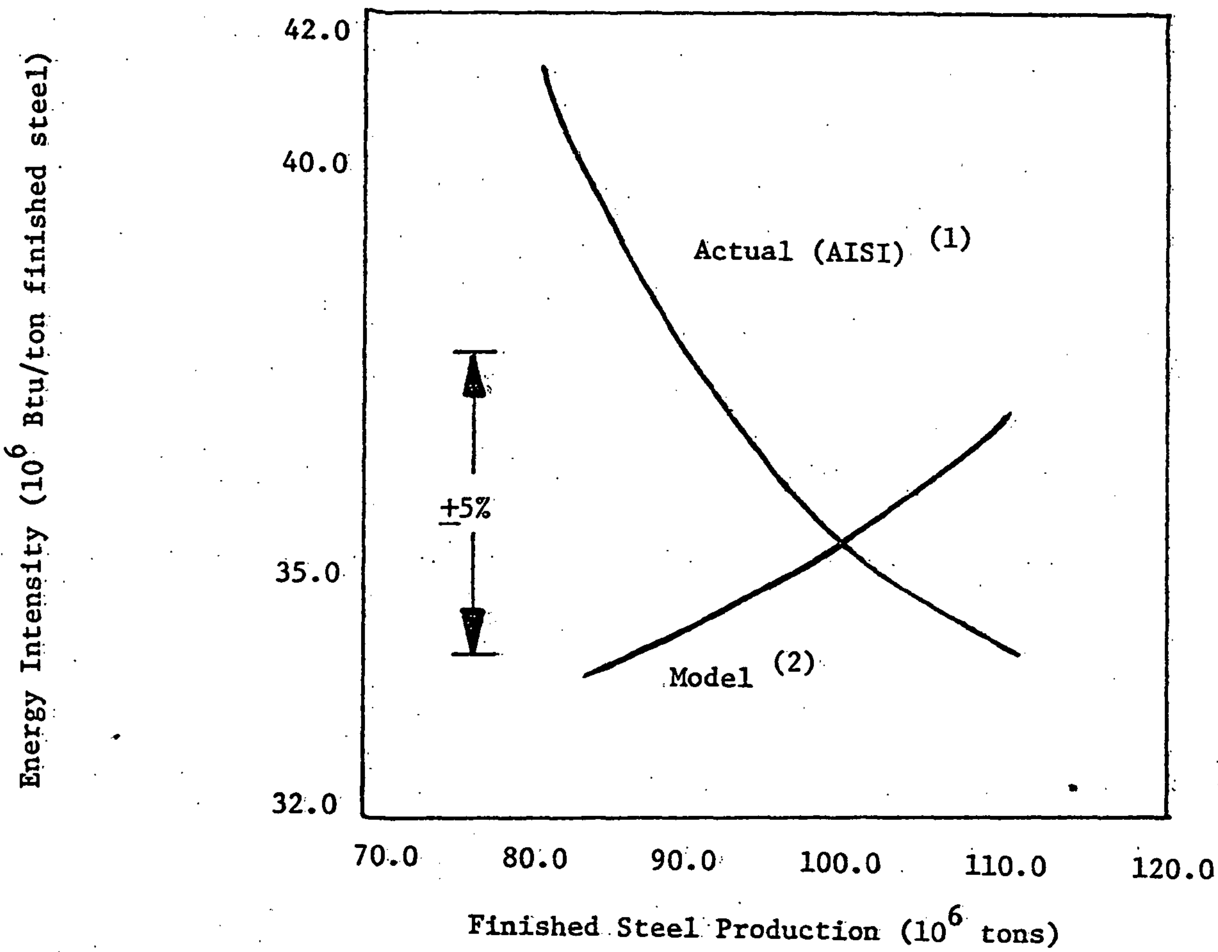
VI. Some Observations

Balance:

Validation is an important activity. Proper performance requires the application of the right kind of resources in the right quantities. Because validation competes with development and application funding, there will be a tendency, in a world where almost all modeling efforts are undersupported, to skimp on validation. The path is indeed a delicate one between

FIGURE 3

Steel Energy Intensity as a Function of Production Level for Mid-1970's



Source: (1) (AISI, 1977)
(2) Model Runs

a suspect, non-validated, but adequate model and an insufficient, but well validated, analytical tool. Hopefully, the internal validation process would preclude the second outcome by recommending that the modeling effort receive more support or be dropped. The balance between validation and development is precarious and perhaps can best be maintained by recognizing that the purpose of validation is to improve the model.

Overvalidation:

A danger that exists with external validation procedures is that most external validators are also modelers and therefore in competition with organizations whose product they are assessing. This relationship may subtly introduce an unintended bias into the evaluation.

Validation Process:

Too often validation consists of recreating history. Yet, the historical path is made up of the interaction of activities subject to physical laws and economic principles, institutions and behavioral responses. Increased confidence is created by manipulating, examining, and comparing explicit activities with the physical and economic laws that they satisfy. This results in a more fundamental understanding of the structure of the systems and the interaction of the individual parts. By explicitly identifying the behavioral interactions and modifying these where appropriate, enhanced understanding is generated as to how and why the system responds to specific policy alternatives or technology options.

Model Limitations:

All models have design limits or ranges over which they can be applied. These are frequently unspecified. It is easy to fall into the trap of pushing the model beyond its limits without realizing it. One weakness of process models is that they do not incorporate invention, only innovation. They are limited to including only those technologies whose economic and engineering characteristics are quantified in reasonable detail. This could lead to an upward bias in energy use when the models are used in a long-term framework if presently unknown energy conserving technologies were invented and implemented during this period. Part of the validation process should be to identify, document, and publicize model limitations.

Models are not all purpose but are designed to test specific hypotheses and provide certain information. Often to decrease modeling costs and perhaps save time, models are adapted that have been developed for other purposes. When this is done, extreme caution is needed to make certain the model is directed to the user's needs and not to those of some earlier user.

Incorporated in any model are biases often unperceived by the modeler or the user. These unrecognized biases are the most dangerous. When bias is introduced by self-interest it can usually be detected and, more important, taken into account; but when bias results from ignorance, limited background, or from blinders imposed by training or experience, it is very difficult to spot. Special efforts must be made as part of validation activities to identify these unrecognized biases.

Relationship with Industry:

For the modeling program described in this paper, cooperation on the part of industry is imperative. Only they know the full pros and cons of embedding any particular energy using process in their productive facilities. Hidden costs, institutional limitations, and perceptions of risk all enter into the decision at the plant level. These factors will be accounted for as our model development program proceeds. Unfortunately, the climate between government and industry has been increasingly hostile. Industry finds itself pulled in many directions by anti-trust regulations that prohibit information sharing, environmental protection regulations asking for nearly the same information, consumerists who misuse information to show how industry is exploiting the consumer, and environmentalists who may use the information to raise the issue of environmental rape. In this environment, industry has an incentive to remain silent. On the other hand, many industry representatives appreciate government's need for better information in formulating policies to influence industrial energy use. Only time will tell how successfully we can solicit industry support.

VII. Recommendations

1. All models and supporting data bases should specify limits, specific assumptions, critical constraints, and unresolved internal validation issues. The documentation should incorporate the questions the model was designed to address and others that it is capable of addressing. The documentation should also include the applications to which the model is not suitable and the boundaries on data or constraints beyond which the model results can not be interpreted meaningfully.

2. The project plan should incorporate a set of internal validation exercises. These should be carried out concurrently with development and application and should be fully documented. The exercises might include sensitivity analyses on input prices, demands, and process coefficients; alternative formulations for input supply curves or output demand relationships; different levels of process aggregation; and alternative institutional arrangements, among others. In addition, at each stage of development and application new questions will be raised, the answers to which will be provided through internal validation activities. This complete set of planned and ad hoc exercises should be documented and available to users and other interested parties.

3. Validation should be considered as a model improvement activity. Care should be taken that it is not misinterpreted by those using the models to discredit the model. Validation expenditures should be balanced with model development expenditures and must include the cost of internal validation documentation. To use validation budgets most effectively, validation concerns should be rank-ordered and the issues examined from the top of the list down until funds are exhausted. If major issues are still unresolved then there is an indication that the program funds are not balanced. In the process of ordering validation issues care must be taken that the validation actions will not be compromised through incomplete or inaccurate validation data.

4. Internal validation guidelines should be generated and published. While their use may be optional at first, they could become a part of all Federal Government modeling contracts as they are modified and improved through experience.

References

A.D. Little, 1978	A.D. Little, Inc., Research Development and Demonstration for Energy Conservation: Preliminary Identification of Opportunities In Iron and Steel Making (1978).
AISI, 1977	American Iron and Steel Institute, Annual Statistical Report for 1976, Washington, D.C. (1977).
DOE, 1977	PL 95-91, Department of Energy Organization Act, U.S. Congress, Washington, D.C. (1977).
Gass, 1977	Gass, Saul J., "Evaluation of Complex Models" in Computer and Operations Review, Vol. 4, Pergaman Press, Great Britain (1977), pp. 27-35.
Gass, undated	Gass, Saul J., Bibliography: Model Evaluation and Assessment, University of Maryland, undated.
Greenberger, 1976	Greenberger, Martin, M.A. Crenson, and B.L. Cressey, Models in the Policy Process, Russell Sage Foundation, New York (1976).
Jordon, undated	Jordon, Robert K., "The Oxygen Blown Blast Furnace Coal Gasifier", unpublished report.
Marcuse, 1979	Marcuse, William, "Why Should Energy Models Form a Significant Policy Input In An Uncertain Political World."
NAS, 1977	National Academy of Science, Applied Research Workshop--AAAS Meeting, Rensaelervalle Applied Research, June 1976, Center for the Study of Man, Washington, D.C. (1977).
Tanenbaum, 1977	"Reflections on Steel's Energy Maze" presented at 85th General Meeting of AISI, New York, May 25, 1977.
Woolf, P.L., 1974	"Improved Blast Furnace Operation" paper presented at Efficient Use of Fuels in the Metallurgical Industries, Chicago, Illinois, December 9-13, 1974.