

**The Validity of Simulation Models  
in Organization Science: From Model Realism  
to Purpose of the Model**

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**THE VALIDITY OF SIMULATION MODELS  
IN ORGANIZATION SCIENCE:  
FROM MODEL REALISM TO PURPOSE OF THE MODEL**

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## ABSTRACT

*"... even though the assumptions of a model may not literally be exact and complete representation of reality, if they are realistic enough for the purposes of our analysis, we may be able to draw conclusions which can be shown to apply to the world."*

*Kalman J. Cohen and Richard M. Cyert (1965)*

Simulation models are widely applied to address fundamental and practical issues in organization science. Yet, simulation modeling in organization science continues to raise questions of validity. In this paper, we argue that simulation validity is a balance of three elements: the question or purpose, the experimental design, and the simulation model. Simple models which address the question are preferred. Non-simple, imbalanced simulations are not only inefficient but can lead to poor answers. The validity approach is compared with well-known validity criteria in social science. Finally we apply the approach to a number of simulation studies in organization science, beginning with Cyert's simulations. They were pioneering and are examples of well designed simulations.





## INTRODUCTION

Can we learn about organizations with simulation modeling? Can simulation models be applied in organization science to test a hypothesis, train a manager, understand organization decisionmaking or aid in the design of an organization? The early contributions of Cyert and his colleagues provide a resounding affirmative response. Their simulation studies help us understand organization decisionmaking, train managers and design organizations. They addressed the validity of simulation models - a question which remains today.

In this paper, we argue that there are three elements which should be kept in balance: the question or purpose, the experimental design and the simulation model. These three form a triangular icon as a reminder that imbalanced design will likely create difficulties in various ways: outcomes are difficult to analyze, the purpose is not met, the simulation model is overly complex. A valid simulation model is one that is effectively appropriate to the end goal.

In the next section, Cyert's pioneering simulation models are described; they focused on the validity question in terms of relevancy; realism was a central issue. Validity in social science studies grew out of concerns for what we can learn from field studies and laboratory studies. Those validity constructs provide a base reference, but are not as directly applicable to simulation studies; nonetheless, the fundamental concerns are the same. We then argue that the three elements: purpose, simulation model and experimental design, should be in balance; a simple model which meets the purpose is preferred. That purpose can be to test a hypothesis, train a manager,

understand decisionmaking or design an organization. Finally, we examine a number of simulation studies in terms of these criteria, beginning with Cyert's simulation studies which are balanced and do effectively and appropriately meet their purpose.

### Cyert's Contributions to Simulation in Organization Science

Cyert pioneered the application of simulation, particularly computer simulation, to organization science. His contributions were not only extensive, but varied in application and approach. Cohen and Cyert's (1965) handbook chapter on simulation of organizational behavior is a detailed summary which also includes other contributions of the Carnegie School. They define (p.305) a model as "a set of assumptions from which a conclusion or a set of conclusions is logically deduced,"; computer models are a special case. Cohen and Cyert focus on the reality of the model:

*It is important to realize that in interesting and useful scientific theories, the assumptions need not be exact representations of reality, but they may instead be reasonable abstractions ... we mean that only certain aspects of reality are contained in the assumptions, namely, those aspects to be relevant.*

The reality of the model is a central issue. But just how close must a model be to "reality" to be relevant. What is a reasonable abstraction? Clearly, totally unrealistic models become abstract fictions. But the question remains; how close is close enough? We suggest that one should look to the purpose, or question being asked, for guidance. They suggest reality itself is an illusive goal, but more importantly, inappropriate by itself.

Cohen and Cyert (p.308) then provide a four category taxonomy of simulation models in organization behavior:

*The four major classes into which we divide simulations of organizational behavior are differentiated according to the purposes for which the models were formulated. First, there are descriptive simulation studies of existing organizations. The purposes of these types of computer models are to formulate theories which explain why existing organizations have behaved in particular ways, to test these theories by comparing the observed past behavior with the simulated behavior generated by the model, and to predict how these organizations will behave in the future. Second, there are illustrative (or "intellective") simulation studies of quasi-realistic organizations. The purposes*

*of these types of simulation models are to explore the implications of reasonable assumptions about organizational behavior, in order to determine what the world is like when these assumptions are true. Third, there are normative simulation studies for designing organizations. The purposes that models of this type serve are to allow us to determine which of several possible forms of organizations are in fact best suited to particular goals we want these organizations to fulfill. Finally, there are man-machine simulations, which are intended to train people to function better in organizational settings.*

"Closeness" to reality is the important concern in the first two categories:

description and illustrative simulation models. Normative models implicitly must be realistic to some degree to be relevant. Finally, man-machine simulations for training people require a level of reality. In this categorization, closeness to reality is a primary concern. However, relevancy can be obtained with simulation models which are not necessarily "close" to reality. The normative studies for designing organizations can be less "realistic" than the descriptive studies, and yet, be quite relevant for the design purpose. Cohen and Cyert provide illustrations of their four categories.

### **1. Descriptive Simulation Studies.**

Cyert, March and Moore (Cyert & March, 1963, p.128-148) developed a simulation model to describe a store buyer's behavior which decides the amount of stock to order and the price to charge. The validation test is to compare the model results with the actual decisions, i.e., a valid model is one which mimics reality. Their model is very close to the actual decisions. In their test, they were very demanding: "unless the predicted price matched the actual to the exact penny, the prediction was classified as incorrect," (p.311). They had 95.4% correct predictions which is very accurate. Nonetheless, generalizability remains an issue, i.e., what do we learn from the study which can be generalized to other situations.

### **2. Quasi-Realistic Studies.**

Cohen, Cyert, March and Soelberg (Cyert & March, 1963, p.149-182) simulated the general behavior of price and output determination in oligopoly firms. The model firm is representative - not a specific firm. The purpose is to illustrate in a quantitative form general hypotheses about oligopoly behavior and derive implications. Price and output determination are the focus decision variables. The firm can be thought of as segmented into three subdivisions - pricing, production and sales. Each operated rather independently, subject to cross department pressures. The model and its decision making behavior are consistent with the behavioral theory of the firm. The multiple goals are attended to more less independently and search routines are adjusted to feedback from experience.

### **3. Normative Simulation Studies for Designing Organizations.**

Two studies are summarized to illustrate normative simulation studies. Bonini (1963) devised a model of the firm made up of three areas: manufacturing, sales and an executive committee. The purpose was to study and manipulate information flows and decision processes to determine effects on firm performance, and hence to suggest changes in the firm's design.

Forrester's (1961) industrial dynamics focusses on how to change policies, organization structure, decision processes and time delays to effect growth and stability. The industrial dynamics model is formulated as an information-feedback system.

Both approaches are clearly normative. The tests of validity are less clear. Realism is important: even so, greater realism may not lead to better recommendations for a change. This difficult question is unresolved.

### **4. Man-Machine Simulation Studies for Training.**

The Carnegie Tech Management Game (Cohen, Cyert, Dill, Kuehn, Miller, Van Wormer and Winters, 1960) was created to train individuals to become more effective managers. Managers, or students, were asked to submit decisions on price, output, etc. for one month. The computer model represented a three firm packaged detergent industry which incorporated parameters and relations for the industry and each company's infrastructure. The computer model determined what happened in this "real world", and presented feedback to participants for another month. It was "developed to mirror more realistically than earlier business games the problems of running a company". Realism is a primary goal for developing the simulation, and implicitly, a more realistic model is a better model, or a more valid model.

Cyert's contributions in simulation modeling are very important to the development of the field. First, his studies were very early, and in many cases the first of their kind. The store buyer behavior model was an early descriptive study. The Carnegie Tech management game was one of the first, if not the first, computer based manager training simulation. Second, the studies span a broad area of application explaining behavior of store buyers to training managers to understand duopoly decisionmaking strategies. Third, Cyert began with the phenomenon itself and let the purpose drive the model, e.g., understanding duopoly strategies - not a model for its own sake. A principle which should drive any simulation modeling.

Yet, realism was also a major concern. The validity of the computer simulation models is tied closely to the realism of the model; however, the relevancy of the model to its purpose is the more encompassing test.

### Validity: Criteria to Keep in Balance

Realism in simulation modeling is clearly germane. Without some degree of realism, simulation becomes a logical and/or numerical exercise. At the other extreme, total realism creates all the experimental and analytical issues that any real world field experiment has. Even management training games yield such a mass of data from a complex model that it is difficult to sort out cause-and-effect relations, or, even devise appropriate statistical tests and controls to test hypotheses. Some realism is mandatory; too much may make it difficult to sort out these cause-and-effect relations and know what we learned and what we did not. E.g., Cyert's duopoly simulation model may provide more insight on decisionmaking than a two firm management game. As a single criterion, there is no way to optimize the degree of realism. We must turn to multi-criteria considerations of validity.

The classic work on the validity issue in social science is Campbell and Stanley (1963). Cook and Campbell (1976) later developed four concepts of validity: internal validity, statistical conclusion validity, external validity and construct validity. Feldman and Arnold (1983) define validity in terms of content, construct, and criterion-related validity. They need answers to the questions: does it make sense to a group of experts, is it measuring the underlying characteristics, and is it related to the real world intent?

As a single criterion, realism is most closely related to construct validity: is (the model) measuring the underlying characteristics (Feldman and Arnold, 1983) or, external validity and the generalizability (Cook and Campbell, 1976). There are other trade-offs to consider in order to obtain balance. Burton and Obel (1984, p. 44-62) compared field experiments, laboratory experiments and computer experiments with respect to internal validity, statistical conclusion validity, external validity and construct validity. They argue



that the computer simulation models score well on all four dimensions when compared with field experiments and laboratory experiments, except for a subcategory of correspondence of the model where field experiments are better. This is the concern for realism and why realism must be addressed in simulation modeling.

Referring to Feldman and Arnold (1983), content, construct and criterion-related validity provide a first level reference for testing the validity of a computer simulation model. (See Figure 1.) Each criterion is an issue, or question and it is difficult, perhaps inappropriate to offer a general response. The content validity: does it make sense to a group of experts, depends upon the model, and the group of experts. The question requires that we must be able to argue persuasively to a relevant group of colleagues that the model captures some important aspects of the phenomenon, for we hope to learn something.

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FIGURE 1  
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**Validity  
Criteria**

**Computer  
Simulation  
Modeling**

**Content:**  
does it make sense  
to a group of experts?

realism

↑

Do the variables,  
parameters and  
relations capture the  
phenomenon of study?

↓

**Construct:**  
is it measuring the  
the underlying characteristics:

realism,  
relevancy

**Criterion-related:**  
is it related to the  
real world intent?

purpose,  
intent,  
questions of interest

**Figure 1**  
**Computer Simulation Validity**

Similarly, construct validity, is it measuring the underlying characteristics, requires that the model and experimental simulation contain parameters, variables and relations which yield outcomes with correspondence to the real world. Finally, criterion-related, is it related to the real world intent, focusses on the intent and how the model and its results be used. Computer simulation models can be used for many purposes. Cyert's simulation models ranged from describing reality to training managers.

All of these criteria relate to an underlying issue of generalizability: can we say something beyond the model itself. Generalizability is related to intent. A model may be generalizable for one purpose and not another. The Carnegie Tech Game (Cohen, et al, 1960) generalizes for training managers. It may be less good as a description of managerial decisionmaking.

These social science validity criteria were originally devised from field experiments and have been applied to other settings. They are general, but not always easily operationalized for computer simulation models. Nonetheless, some issues seem clear. Validity is a multi-criteria issue. There are trade-offs among the criteria, i.e., a model and/or experiment will not meet all criteria perfectly (McGrath, et al, 1982). A good model and experiment is one which meets its purpose, and we need to understand the purpose of the computer simulation model.

### **Validity in Simulation Models: In Praise of Simplicity and Balance**

The validity of the simulation models requires multiple considerations and trade-offs among the various criteria. We shall argue that balance and simplicity should be overriding concerns in devising a simulation model. Occam's razor applies to simulation models and we seek parsimonious explanations.

In developing a simulation model, we propose a balance among the following considerations:

- purpose,
- model and simulation,  
and,
- experimental design and data analysis.

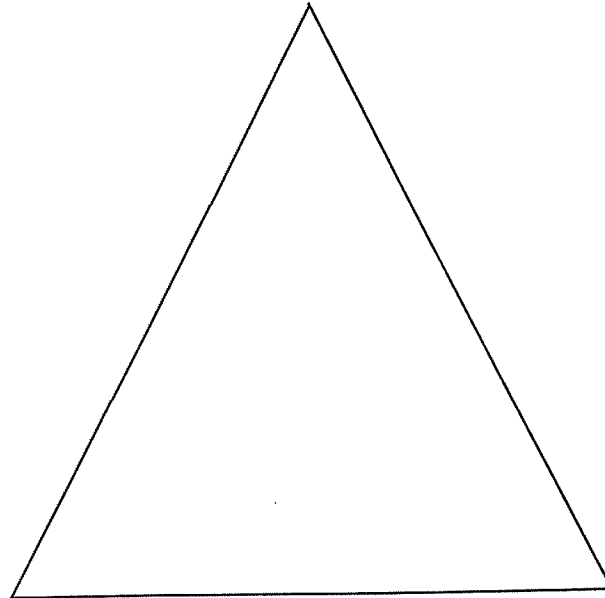
In Figure 2, these considerations are placed in a triangle to suggest that a balance of all three is required.

The purpose of the simulation provides the anchor. Usually, we are trying to answer some question. Before the model is devised and results analyzed, we should be able to say that whatever results are obtained, we will have answered, at least in part, the question and met the purpose. Criterion-related validity is a similar concern. Cyert's simulation models were clear in purpose: describe the organization and its decision making processes, or to train managers. Each purpose suggested a different simulation model. We can also add that simulation models can be devised to: test hypothesis, explore organizational processes, generate theoretical issues, and eliminate alternative explanations. This list is representative, not complete.

The model, i.e., the statement of the parameters, variables and relations, can now be stated to meet the purpose. Cyert's descriptive model of buyer behavior included decision making variables on price and stock levels and associated parameters and relations to create the model. The model contained nothing on the buyer's happiness - it was not the purpose to explain happiness. The simulation is an explicit set of instructions on how to operate the model, i.e., run or update the model. In a computer simulation model, a program, or set of instructions, is required. The Cyert models were discrete time models, each required an algorithm to update the program from one period to the next period. The Carnegie Tech Game simulation was updated by the computer

program which incorporated the participants' decisions. The model statement of variables, parameters and relations and the simulation process must fit together and can be thought of as the simulation model.

Purpose: Goal, what do we want to accomplish?  
 Description of the behavior  
 Advice or Normative Model  
 Training  
 Hypothesis Testing  
 Exploration  
 Theory Generation



Model,  
Simulation

Experimental Design,  
Data Analysis

**Figure 2:  
Simulation Model Design:  
Balance and Simplicity\***

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\* The triangle of purpose, model and simulation, and experimental design and data analysis is an icon. There are five elements and a pentagon is an alternative icon. Each pair: the model and simulation, and the experimental design and data analysis, are so closely tied we chose the triangle.

The experimental design and data analysis are closely linked. The experimental design question is: how is one going to manipulate the simulation model or change parameter values so that the model outcomes permit us to meet the purpose, or help answer the question. Usually, the data analysis is analysis of comparisons for different parameter values to test a hypothesis. The comparison in the Cyert buyer model was to compare the simulation model results with the real world buyer behavior - which is perfectly matched for a descriptive purpose. Here, the parameters were adjusted to meet the descriptive purpose. Again, the experimental design and data analysis are closely linked so that the data analysis can be as simple as possible to meet the purpose. In the extreme, it is easy to create manipulations which yield data which are impossible to analyze. However, such an approach could meet an exploratory purpose.

Plott (1982, P. 1520) in his defense of experimental economics, notes that laboratory markets are "real" markets in that basic economics principles must apply - general theories should apply to special cases. Simulation models are special cases by their very nature; indeed, we want special cases which are relevant, but always less than "real". The trick is to create a simplicity which meets the purpose and addresses the question being posed; and there is an advantage in simplicity.

The argument for simplicity and balance is partly one of economy. We want to devise a simulation model and experimental design which meets the purpose. All three of these issues can be dealt with simultaneously in the beginning. With a clear statement of purpose or goal, the simulation model and experimental design can be devised to meet the purpose.

However, the argument for simplicity goes beyond economy. Complex models are not only more expensive to devise, but may require statistical data analysis problems

which limit our ability to address the question. E.g., a descriptive purpose requires a realistic model. Hypothesis testing does not necessarily require a realistic model. The more complex model may introduce complexities which may be difficult to sort out in the data analysis. Thus, the purpose or question may be missed. The simulation model and experimental design must be sufficiently complex to meet the purpose, but greater complexity can be detrimental. (Burton and Obel, 1984)

This greater complexity is a threat to construct validity (Cook and Campbell, 1976). High construct validity requires that the potential causes and effects are carefully defined so that results can be sorted out. E.g., if the experiment involves a factorial design then only a few factors can be manipulated and maybe only with discrete variation. However, the nonmeasured and noncontrollable factors may be the underlying determinations of the result (Burton and Obel, 1984, p. 54). Of course, these issues can be controlled statistically, if we can know a priori the potentially explanatory variable. We are arguing that it is preferable to eliminate these complexities in the design of the simulation model itself, and not be forced to rely on sophisticated statistical analyses. There is a lesser risk of these false inferences from simple models and experiments than complicated ones. Simplicity and economy are the basic.

### **Balance and Simplicity in Organizational Simulation Models**

Simulation models in organizational science come in a wide variety of forms: large and small, realistic and less so, computer only, computer aided, normative and descriptive, experimental and exploratory, etc. None are necessarily valid, nor invalid. We have argued that simplicity and balance of purpose, simulation model and experimental design provide a validity focus.



Simulation modeling in organizational science is rich in its diversity of application and approach. Nonetheless, they can be analyzed within these validity frameworks. We review a number of organizational science simulation studies and applications. We begin with Cyert, Feigenbaum and March's behavioral theory of the firm duopoly model.

### **Behavioral Theory of the Firm Duopoly Model**

Cyert, Feigenbaum and March's (1959) purpose was to gain a better understanding of the decision-making processes in the duopoly firm. The decision variables of interest were how much to produce and what price to charge. Unlike analytical equilibrium duopoly models, the computer simulation model focussed on the complexities in decision-making and understanding of organizational processes. The organizational decision-making characteristics depend upon " ...information, estimates and expectations that ordinarily differ appreciably from reality... organizations consider only a limited number of alternatives... conflict and potential conflict of interests is a feature of most organizations..." (p. 82). With this purpose, goal and general characteristics of the firm, the model and the simulation needed to capture this level of complexity and incorporate decision-making processes.

The nine step decision-making process outlines how the computer simulation is to be run. (See the appendix for greater detail.) The model is a specific duopoly model. The simulation process and the duopoly model are closely tied and comprise the simulation model. It follows from and matches well the purpose of gaining a better understanding of the decision-making process.

The experimental design was explicit in stating beginning conditions and following a large number of variables over time; aspiration level, outputs, prices and profits. The

data analysis compared the simulation model results with the actual data from American and Continental Can companies from 1913 through 1926. The results suggest that the simulation model yielded results of the same level and directionally similar to the real data. The purpose of the simulation model was to understand better decision-making processes. In observing the model major business decisions close to the actual decisions, it can be inferred that the complex nine step decision-making process and its characteristics capture essentials of the actual decisionmaking process. However, it does not eliminate alternative explanations. The authors (p. 94) close with "we need a great deal of work in actual organizations identifying the decision procedures used in such things as output decisions," and a call for human decision-making in the laboratory under conditions found in business organizations.

In terms of the purpose, simulation model and experimental design-analysis, this simulation study is clear and balanced. The purpose is to gain a better understand of duopoly behavior; the simulation model spells out the variables, parameters and relations, and how the simulation will be run; the experimental design and data analysis are designed to test the behavioral theory of the firm propositions. The balance is appropriate. The model itself is a representative model and it is relevant, but is not a real world replicate. Would more have been gained with greater realism; it is questionable. The clarity of the results may have suffered. Could a simpler model have been devised? The purpose was to understand the decision-making processes - not just the decision results. Simpler models eliminate the decision-making process and do not meet this purpose. This duopoly model illustrates the balance and simplicity of simulation models.

### **The Carnegie Tech Management Game**

Cohen, et al. (1960) developed the Carnegie Tech Game to help future managers become better managers in an environment of complexity and realism.

The model was based on the packaged detergent industry. It was a national market with a few firms with differentiated products. The model included production, marketing and finance variables. The simulation was a two step process. First, the teams analyzed the data about the market environment and the internal production situation, and then, made decisions on prices, production, etc. Second, the computer model replicated the firms' environment and created outcomes including firm profits.

The experimental design tested how well the future managers forecasted and planned in this complex situation, and how well the teams worked together. The outcomes analysis is largely qualitative.

The Carnegie Tech Game was a great step forward to create more realistic management games for future managers and remains the base model for sophisticated management games. Realism is an important concern to meet the purpose here. This meets the purpose of training managers.

### **The Garbage Can Model of Organizational Choice**

Cohen, March and Olsen (1972) devised a computer simulation model of organizational anarchy where decision-making processes do not proceed in the usually presumed rational manner. In the garbage can, there are choices looking for problems, feeling looking for venues to be aired, solutions looking for problems and decision-makers looking for work. It is a complex situation which proceeds according to a "new" rationality; is this possible?

The purpose is to offer a plausible explanation for the existence and viability of the garbage can and explain how reasonable decisions can be made in such disorder. The model contains four basic variables: stream of choices, stream of problems, flow of solutions and streams of energy of participants. The relations include energy allocation and problem allocation assumptions.

The experimental design required the manipulation of the organizational structure to affect the organizational outcomes on decision style, problem activity, problem latency and decision-making activity and decision difficulty. The analysis generated a number of implications. They provide some answers to the questions whether the garbage can is possible, and insights on how it is possible. The analysis yielded these implications:

- resolution of problems as a style is not the most common style,
- the process is sensitive to variations in load,
- a tendency of decision makers and problems to track each other through choices,
- important interactions among problem activity, problem latency and decision time,
- the process is frequently sharply interactive,
- important problems are more likely to be solved than unimportant,
- important choices are made by oversight and flight; unimportant by resolution,
- and
- choice failures appear among the most and least important choice.

The garbage can studies are well-balanced. The purpose is clear to understand the organized anarchy. The model includes the variables, parameters and relations to meet the purpose. The experimental design and data analysis yielded results which provide answers about the organized hierarchy.

### **Designing Efficient Organizations**

Burton and Obel (1984) developed a hierarchical decision-making model for assessing the effect of various organizational decisions on the firm's performance. It is a

multi-agent model which incorporates individual actions and information of flows. The general model could be modified to incorporate a M-form or U-form organization, tightly or loosely linked technology and price or budget resource allocation schemes under various levels of uncertainty. The simulation process mimicked the up-down-up interactive planning processes in hierarchical organizations. Each specific model, e.g., M-form with loosely linked technology, must fit the simulation process, e.g., the budgeting of resources. The model was simulated on the computer.

The experimental designs were classical 2-way complete factorial designs where the dimensions were the contingencies of interest. The data analysis utilized non-parametric statistical tests to test hypothesis on organizational forms, technology and resource allocation schemes. One particular simulation tested the effect of a M-form vs. U-form and loosely linked technology vs. tightly linked technology, holding the price directed resource allocation scheme constant. Four specific models and simulation procedures were developed to realize the required experimental variations, or manipulations. The 2 x 2 complete factorial experimentation design yielded four outcome cells. Hypotheses on organizational form and technology linkage were tested using nonparametric statistical tests on the data. In brief, the M-form performed better for the U-form organizational, but particularly so for loosely linked technology. Loosely linked technology is easier to coordinate than tightly linked technology in a hierarchical organization.

A related laboratory experiment (Burton and Obel, 1988) was developed on the same general model. Within the hierarchical organization, one division was played by an individual; the other divisions and headquarters were run by the computer simulation. The research question was to test the opportunism proposition: would individuals

understand a situation to be opportunistic, could they figure how to take advantage of the situation and would they take advantage (Williamson, 1975)? Yes, individuals readily understand an opportunistic situation, almost all knew how to be opportunistic, and many took advantage, but some were altruistic in their behavior.

Laboratory experiments and computer simulations are very close, especially when the computer simulation models contain well defined individual or organizational unit roles.

These simulations were devised to test hypotheses concerning alternatives in the design of the firm. The model is a small hierarchical model where the variables, parameters and relations, together which the simulation runs mimic the hierarchical decision process. The experimental design and data analysis were chosen to permit the simplest of statistical tests for the hypotheses. The purpose, simulation model and experimental design are balanced to provide the simplest model and simplest statistical test to meet the purpose of testing organizational design hypotheses.

### **Agent Honesty, Cooperation and Benevolence**

Carley, Park and Prietula (1993) extend the SOAR model to investigate the effect of three variables: agent honesty, cooperation and benevolence, on form outcome variables: cognitive effort, physical effort, communication effort and wait time. SOAR is a multi-agent artificial organization which incorporates individual cognitive capabilities, e.g., problem-solving and memory and here, individual characteristics in an organization with various information flows. Each agent searches through a problem space to satisfy goals. The simulation model is a computer model which is run through time to replicate the organizational process of problem solving.

The experimental design is a 2 x 2 x 2 complete factorial design; varying the organizational size from 1 to 5. The observed outcomes for the four variables; cognitive effort, physical effort, communication effort and waiting time are analyzed for general patterns. The U-shaped total cognitive effort vs. organizational size is demonstrated as well as the orthogonality of physical and social effort.

The purpose, simulation model and experimental design are well balanced - each has devised in light of the other requirement. There is no excess baggage, but only those essential elements of reality in the SOAR to meet the purpose.

### **The Virtual Design Team**

Having observed that engineering project design relies on adaptation of past organization structures, Levitt, et al. (1993) employ ideas from AI for modeling the behavior of full-scale organizations. The purpose is to predict task duration for engineering design teams in carrying out routine designs.

The model is an information processing model of an organization: tasks, actors, communications, tools and structure. The actors are boundedly rational. Each player operates in an "in-tray, out-tray" environment supported by communication tools.

The computer simulation processes the set of tasks for a project network - a three-year petroleum refinery design project. The experimental design is a 2 x 2 design; one dimension is centralized, decentralized organization, the other voice mail, without voice mail. The null hypotheses are that the organization structure and the voice mail do not affect the work-hours required to complete the project design. They found that a decentralized organization required lower total work-hours, and voice mail reduced the total effort required.

These studies have a broader purpose of modeling the design process as well as the specific purpose of predicting task duration and testing related hypotheses. The refinery design project model is more than sufficient for the specific purpose; but the more complex, more realistic design project is required for the more general purpose. However, the greater complexity does not create data analysis issues in testing the specific hypotheses. Not infrequently complex models create data analysis problems; the appropriate experimental design and manipulation guide this relation.

### Related Simulation Models

Simulation models in organization science are extensive and varied. In this section, we briefly review three studies which extend the previous simulation models.

Masuch and LaPotin (1989) build on the garbage can model to combine "ambiguous choice with decision-making under structure." They utilize new AI tools to overcome some limitations in the original model which did not incorporate organization structure. "Organizations subdivide activity by structuring the access of individuals to tasks as well as their access to other individuals" (p. 45). They found that decision-making in organized structures may also become disorderly, but in different ways than in an organized anarchy. "Fluid participation is not the sole cause of messy decision-making; ordinary hierarchies don't work well, provided that actors are constrained by bounded rationality," (p. 60). A related, perhaps surprising result is that "Low workload can reverse the influence of commitment on productivity, because committed actors, in search of work, spend too much time attracting issues from each other, issues are always on the move, and little gets done," (p. 61).

Harrison and Carroll (1991) take simulation modeling in a different direction: cultural transmission in a formal organization. They want to know whether an



organization's culture can be transmitted over time, where members come and go rapidly. The cultural system consists of a hiring function, a socialization function, and a turnover function. Individual enculturation is embedded in the socialization function. In contrast to other studies, there is no explicit decision-making model, but behavioral functions. They demonstrate that "cultural systems in organizations are highly robust and reach equilibrium even with high turnover and rapid growth" (p. 552). Model parameters are systematically varied to represent various organization forms, eg., Japanese, American manufacturing, bureaucratic, entrepreneurial, etc. Perhaps not surprisingly, Japanese forms had higher levels of enculturation than American manufacturing. Organizations in decline had stronger culture than those in growth, which may be less evident. They have demonstrated the dynamics of culture of the organization.

Finally, we return to an early study by Bonini (1963): simulation of information and decision systems in the firm. The purpose was to study the effect of informational and organizational factors upon the decisions of the firm. The model contained decision centers, information centers, decision rules, and information links to create a total system of a hypothetical firm. The simulation involved running the model for 108 periods, allowing some stability in the outcomes. The experimental design was a fractional factorial design to estimate main effects and interactions, requiring sixty-four runs. Eight changes were made to test eight null hypotheses on inventory rules, sensitivity to pressure, salesforce knowledge of inventory, stability of external world, etc. The data were analyzed to test the hypotheses. Bonini's study remains an excellent illustration of attention to purpose, simulation model, experimental design and analysis.

## SUMMARY

Cyert's pioneering studies began with a consideration of validity, i.e., is it relevant to the purpose. Realism then became a derived issue to make the studies in description and training, in particular, relevant. Validity in the field and laboratory studies in social science grew from a different, but related, set of concerns. However, the social science validity concerns can be operationalized for simulation model studies in organization science.

Simulation models provide more flexibility in their construct. We argue that the simulation model can be devised with simultaneous consideration to: the purpose, the simulation model and the experimental design. The triangular icon represents three criteria to keep in balance, and this balance is realized by creating simple simulation models and simple experimental designs which meet the purpose or intent of the study. In the last quarter century, there have been numerous simulation studies; some of which we review in terms of our three criteria. Cyert's early studies provide an approach to simulation models in organization science which illustrate the fundamental concerns of validity and how to address them, although model realism was a concern, the underlying purpose of the simulation was paramount..

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**APPENDIX**

Reference: Cyert, R. M., E. A. Feigenbaum and J. G. March (1959). "Models in a Behavioral Theory of the Firm." Behavioral Science, vol. 4, pp. 81-95.

### Behavioral Theory of the Firm

- **Question:** How do business organizations make decisions? What processes do they follow?
- **Objective:** Show how the general attributes of decision-making can be introduced into a behavioral theory of the firm.
- **Model:** A specific type of duopoly
  - Product is homogeneous
  - Only one price exists in the market
  - Major decision for each firm is an output decision
  - In making this decision, firm must estimate the market price for varying outputs
  - No discrepancy between output & sales is assumed
  - Actual selling price determined by the marketplace
  - Duopoly consists of an ex-monopolist and a spin-off
  - Compare data from the models with data from the can industry
- **Simulation:** Define nine distinct steps in the price and output decision process
  - Forecast competitors behavior
  - Forecast Demand
  - Estimate Costs
  - Specify Objectives
  - Evaluate Plan
  - Re-Examine Costs
  - Re-examine Demand
  - Re-examine objectives
  - Select alternative
- **Experimental Design:** A relatively complex model of the firm as a decision-making organization including aspiration levels was developed and used to yield economically relevant and testable predictions of business behavior.
  - Compare the predictions of the model with the actual data.
- **Analysis:** Results of model were compared to that of actual data from American and Continental Can companies from the period of 1913 through 1956. Analyses are given in graphical and tabular format.

Reference: Cohen, K. J., R. M. Cyert, W. R. Dill, A. A. Kuehn, M. H. Miller, T. A. Van Wormer and P. R. Winters. "The Carnegie Tech Management Game," The Journal of Business, vol. XXXIII, no. 4, Oct. 60, pp. 303-321.

### Carnegie Tech Management Game

- **Question:** Do management games provide an effective training tool for improving (decision-making) performance in particular organizational settings or for training future business executives.
- **Model:** Packaged detergent industry.
  - Major features include the existence of a national market, a small number of firms, and a set of differentiated products.
  - Variables (supplied by models)
    - Production: raw materials situation, factory performance, & warehouse transactions
    - Marketing: expenditures by product and region, info on the economy, sales by brand
    - Finance: info on money & capital markets, balance sheet, income statement.
  - Decision variables (set by teams)
    - Production: orders of raw materials, size of labor force, overtime, maintenance of P&E, production allocation, and amount of transshipments
    - Marketing: prices & advertising & distribution expenditures by region & product
    - Finance: net cash requirements for operations, allocate shares of profits, how to cut expenditures, authorize total receipts.
- **Simulation:**
  - Teams are responsible for analyzing data about the market environment and making a host of decisions in three facets of the business, financial, production, marketing.
  - Their decision variable levels are put into the computer and the results of their decisions along with the new states of nature are reviewed and the cycle is repeated.
- **Experimental Design:** Design a game/experiment where the participant's are (1) tested in their ability to forecast and plan; and take action to achieve desired outcomes in a complex and diffuse environment; combine roles of generalist and specialist; and work effectively with other people and (2) provided with opportunities to develop said skills.
- **Analysis:** There appears to have been no follow-up or discussion as to whether the participants did actually become better managers, decision-makers, etc. It is mentioned that the game has been added to the CMU curriculum for MS and Ph.D. students in GSIA but again no data are available for the degree to which there has been improvement in their managerial expertise or knowledge. A four member faculty "Board of Directors" is assigned to each firm and they judge the rate of progress of the team members through face-to-face meetings and through examination of written reports.

Reference: Cohen, M. D., J. G. March and J. P. Olsen. "A Garbage Can Model of Organizational Choice," Administrative Science Quarterly, vol. 17, pp. 1-25, March 1972.

### Garbage Can Model of Organizational Choice

- **Question:** How is it possible that organization can make decisions despite pervasive apparent disorder inherent in the decision making process?
- **Model**
  - **Independent Variables:** A stream of choices, a stream of problems, a rate of flow of solutions, and streams of energy from participants.
  - **Fixed Parameters:** number of time periods, number of choice opportunities, number of decision makers, number of problems, solution coefficients.
  - **Dimensions of an organization:**
    - Entry Time - two randomly generated sequences of entry times for choices are considered, as are two for problems.
    - Net Energy Load - three levels - light, moderate and heavy.
    - Access Structure - unsegmented, hierarchical and specialized.
    - Decision Structure - unsegmented, hierarchical and specialized.
    - Energy/Distribution - important people / less energy, equal energy, important people / more energy.
- **Simulation**
  - FORTRAN program
  - $81 = 3^{**}4$  types of organizational solutions (obtained by taking the possible combinations of the values of four dimensions of an organization) are studied here under the four combinations of choice and problem entry times. The result was 324 simulation situations.
- **Experimental Design:** Various organizational structures are manipulated to create 324 situations to affect organizational outcomes; time patterns of choices, solutions or decision-makers, energy allocation and linkages.
- **Analysis:** Talks about model as if testing it were the experiment rather than the experiment being how well the model predicted the performance of an organization??
  - Resolution of problems as a style for making decision is not the most common style, decision making by flight and oversight is a major feature of the garbage can process.
  - The process is generally sensitive to variation in the load.
  - A typical feature of the model is the tendency of decision-makers to track each other through choices.



- The process is frequently sharply interactive.
- There are important interconnections among the three aspects of the efficiency of the decision processes specified (problem latency, problem activity, and decision time).
- Important problems are more likely to be solved than unimportant ones.
- Important choices are made by oversight and flight. Unimportant ones are made by resolution.
- Although a large proportion of choices are made, the choice failures that do occur are concentrated among the most important and least important choices.

Reference: Burton, R. M. and B. Obel (1984). Designing Efficient Organizations: Modeling and Experimentation, Amsterdam, North Holland.

### **Designing Efficient Organizations: Modeling & Experimentation**

- **Question:** How do important contingencies of form, technology and decision-making approach affect the firm's performance.
- **Model:** A hierarchical decision-making model to allocate scarce, shared and unit-specific resources. The general could be made specific for various organizational forms and contingencies.
- **Simulation:**
  - Manipulate contingency parameters of interest.
  - Iterative planning procedures to replicate the planning process in hierarchical organizations.
- **Experimental Design:**
  - Classical 2-way (eg., 2 x 2) complete factorial designs where the performance outcomes were unit and firm profits.
- **Analysis:** ANOVA analysis using nonparametric analysis to test hypotheses on organizational form, technology linkages and resources allocation schemes.

Reference: Carley, K., D. Park and M. Prietula (1983). "Agent Honesty, Cooperation and Benevolence in an Artificial Organization," Washington, D.C., AAAI Proceedings.

### Agent Honesty, Cooperation and Benevolence in an Artificial Organization

- **Question:** Organizations are composed of individuals yet organizational behavior is not the sum of the behavior of these individuals. Is there a way in which we can bring insight to the complex relationship between the individual behavior and action, and the behavior of the organization to which they belong?

- **Model:** SOAR

#### Basic Characteristics:

- Reflects a comparatively complete general architecture for reasoning & problem solving.
- "Theory of the agent" is employed in form of a computer program.
- Agent's capabilities defined in terms of knowledge incorporated into SOAR architecture.
- Capabilities of organization are defined by aggregate capabilities of its agents.
- Some capabilities directly reflect observable organizational events while others are endogenous to the agents and less visible.
- Proposes mechanisms for learning and goal-driven behavior (which guides learning).
- All SOAR behavior is characterized as a search through problem spaces in service of satisfying goals.
- If an impasse is reached, new goal is generated to resolve it, resulting in the engagement of a new or different problem space and the knowledge contained in it.
- In order to have SOAR do a task, it is necessary to code tasks knowledge in the form of SOAR productions. A collection of productions is called plural-SOAR.
- In this paper, plural-SOAR is extended by adding social memory or reliability of other agents' information to the agents.

- **Simulation:**

- Run the model overtime.

- **Experimental design:**

- Examine the effect of three social agent behaviors (cooperativity, reliability and benevolence) on four measures of organizational performance: cognitive effort, physical effort, communication effort and idle time.
- Cognitive effort measured as the number of decision cycles required to solve problem.
- Physical effort is the sum of the number of agent movements.
- Communication effort: sum of the number of times agent asked, answered, evaluated, etc., answers.
- Wait time: amount of idle time agent spent waiting for other events to happen.
- For each of 8 cells in the 2 x 2 x 2 design, five different organizations were simulated.
- Organizations differed in number of agents, one to five.
- The 40 Run times varied from five minutes to several hours.

- **Analysis:**

- Observations in within each 2 x 2 x 2 design, then analyze of variations as a function of organization size.

- The orthogonality of physical and social effort was demonstrated.
- Physical effort became less on average for the organization as number of agents working conjointly increased.
- Social effort (communication effort & wait time) increased with number of agents.
- A u-shaped curve for total cognitive effort vs. organizational size was demonstrated and found to be the result of three curves (physical and communication effort and wait time). The first curve is monotonically decreasing while the other two are monotonically increasing with organization size.

Reference: Levitt, R. E., G. P. Cohen, J. C. Kunz, C. I. Nass, T. Christiansen and Y. Jim (1993). "The Virtual Design Team: Simulating How Organization Structure and Information Processing Tools Affect Team Performance," K. Carley and M. Prietula (Eds.), Computational Organization Theory, Hillsdale, NJ, Lawrence Erlbaum.

### The Virtual Design Team

- **Question**

- Managers designing large scale organizations to carry out complex tasks still rely on adaptation of past organization structures, rather than on systematic generation and evaluation of alternatives, in designing their organizations.
- VDT is an effort to employ ideas from AI for modeling the behavior of full-scale organizations.

- **Model**

- In VDT, an organization is an information processing and communication system, structured to achieve a set of tasks (objectives) and comprised of limited information processors (individuals or sub-teams).
- These information processors send and receive messages along specific lines of communication via communication tools with limited capacity.
- VDT can serve as a facility to formulate and test specific conjectures regarding the qualitative effect on project cost and duration of changes in the organization structure of the team, or in the communication tools available to the participants.
- VDT is a computational discrete event simulation model incorporating qualitative reasoning concepts derived from AI research.
- Inputs to the VDT are:
  - A description of the task and the subtasks that compromise it, including sequential dependencies between subtasks.
  - A description of the actors in the design team and of their organizational structure.
  - A listing of the communication tools (FAX, voice mail, etc.) available to each actor.
- Model output is:
  - A prediction of total processing time required to process all subtasks.
  - A prediction of the duration to complete the entire design project along the critical path through subtasks.

- **Task**

- VDT was tested by observing and modeling a large petrochemical design project. The project was selected because the engineering design issues were well understood and without significant or novel technical problems.
- Thus, the task of the design team is the completion of a set of pre-determined activities - the design, review, and approval of a series of components or sub-systems of the artifact to be designed.

- Activities are modeled as being interdependent.
- Each activity description includes the magnitude of the activity, expressed in terms of:
  - The expected number of communications to satisfy its objectives.
  - Precedence constraints with related activities
  - Complexity
  - Variability
  - Percentage completed
  - Budgeted duration
- **Communications**
  - Completion of each activity involves processing the number of communications specified by the activity's magnitude.
  - VDT represents three basic types of communications
 

Design communications - which carry the info required to perform specialized design activities.  
 Exceptions - which are generated by VDT to initiate review or approval decisions.  
 Noise - which consumes time of design team participants but is irrelevant to accomplishing the task.
- **Actors**
  - Actor designs include:
    - Role Characteristics
    - Individual attributes
    - Natural idioms of communications that actor processes most effectively
  - Actor executes the following behaviors:
    - Select (stochastically) communications from an in-tray
    - Process Information - where the time to process a communication depends (stochastically) on the task attributes, nominal duration, degree of variability, and the match between the capabilities of an actor and the requirements of the task
    - Send Communications to other actors
    - Generate Activities to coordinate with other actors
- **Tools**
  - Each communication is transmitted via a tool selected by an actor.
  - Each tool is represented in terms of the values on a set of variables that are theorized to affect both the choice of tool and results of that choice.
  - Tools are characterized by their:
 

synchronicity	cost	recordability
proximity to user	capacity	bandwidth

- **Organization Structure**
  - Structure in VDT is defined by a set of organizational relationships among actors, and levels of authority of actors in specific roles.
  - Relationships modeled in VDT include:
    - Supervised by: to implement hierarchical structure
    - Coordinates with: to implement lateral relations
    - Socializes with: to implement informal structure
  - A set of project-specific coordination policies assigns decision-making authority to actors in particular roles.
- **Simulation**
  - Model was implemented on a SUN Microsystems IPX Sparcstation using the Knowledge Engineering Environment (KEE) and SimKit discrete event simulation system, both from Intellicorp.
  - A typical case run has:
    - 24 activities
    - 17 actors
    - approximately 1 million simulation events
    - takes 90 minutes to run on a 64 MB Sun IPX workstation
  - Runs were also conducted with as many as 90 activities and produced qualitatively identical results.
- **Experimental Design**
  - In order to validate VDT on a real world organization, they modeled a 3-year petroleum refinery design project having:
    - A total design/construction cost of approximately \$130 M
    - A budget duration of 20 months
    - At its peak, approximately 120 personnel in two offices
  - All actor and task descriptions were derived from this project and held constant
  - Candidate organization had a decentralized structure and provided voice mail to its designers.
  - Validation experiment preceded as follows:
    - Select two relevant variables to test - level of centralization and availability of voice mail. Set all other variables at average values
    - use Galbraith's to make a qualitative prediction when changing each of the two test attributes
    - Conduct a set of three simulations of VDT for each pair of values of the two independent variables, for a total of twelve simulations
    - Compare simulated vs. theoretically predicted results using standard statistical measures of significance

- **Analysis**
  - **Simulation Results**
    - A two-way ANOVA indicated that centralized decision-making leads to longer task duration than does decentralized decision-making
    - Also as predicted, removing voice mail increases the duration of the project
    - The interaction between voice mail and centralization is not significant
    - For both, centralized and decentralized organization structures, voice mail improves performance, as predicted
  - **Model Limitation**
    - VDT can only model routine tasks
    - VDT's predictions of duration, although quantitative, must be interpreted qualitatively at this stage.
    - Galbraith's theory and the current VDT model are not explicit about the issues of decision-making quality, so they can not model the trade-off between project duration and quality
    - The next VDT model will extend the current model by explicitly representing and reasoning about the functional requirements of each subtask