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THE UTILIZATION OF THE BEHAVIORAL SCIENCES IN LONG RANGE FORECASTING AND POLICY PLANNING

Stuart J. Thorson

Ohio State University Research Foundation

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S. J. Thorson

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The goals of the project have been the development of forecasting techniques to the point where the impact of alternative U. S. foreign policies toward specific countries can be assessed in alternative strategic environments. As a way of achieving this objective, the Project is developing computer simulations of several Middle-East oil producing nations. In doing this, assumptions about relations between U. S. policies and policy actions and country and region specific indicators of stability are being expressed in a mathematical language.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) results from current ARPA supported basic research efforts are being used to provide a basis for defining and testing the relations between these indicators. In a future phase of the Project, mathematical control theory and (subjective) dynamic programming (augmented with user stated objectives in each country) will be applied to identify "best " mixes of U. S. policy toward each country.

As a substantive target, U. S. relations with Saudi Arabia, Iran, Iraq, Libya, and Algeria are being studied. Thus far the emphasis has been upon Iran and Saudi Arabia. Each country simulation is divided roughly into four modules and agriculture module, an oil module, a human resources and national accounts module, and a government or "decision-making" module (this structure is shown schematically inFigure 1.1). In order that these simulations have maximal impact upon the policy planning community and in order to take advantage of the knowledge of the planners, the simulations are being developed in close interaction with policy planners in both the Defense and State Departments.

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1. INTRODUCTION

1.1 Project Overview. One of the goals of this project has been to develop computer based simulation models of a type which might be used in assessing the impact of alternative U.S. foreign policies toward specific countries under alternative strategic environments. To achieve this objective, the Project is developing computer simulations of several Middle-East oil producing nations. In doing this, assumptions about the relations between U.S. policies and policy actions and country and region specific domestic indicators are being expressed in a mathematical language. Results from ARPA supported basic research efforts are being used to provide a basis for defining and testing the relations between these indicators.

As a substantive target, U.S. relations with Saudi Arabia and Iran are being examined. Each country simulation is divided roughly into four modules - an agriculture module, an oil production module, a human resources and national accounts module and a government or "decision" module (this structure is shown in Figure 1.1). In order that these simulations be of a type potentially usable by the policy planning community and in order to take maximal advantage of the knowledge of planners, the simulations are being developed (with the assistance of CACI, Inc.) and evaluated in close interaction with policy planners in both the Defense and State Departments.

A second Project objective, in some senses derivative from the first, is to provide an overall assessment of the utility of analytic and computer simulation models in policy planning. While some work along this line has been completed during the last six months (see PTP Working Papers 34, 35,39), the majority of the technical work is scheduled for the last eight months of this contract.

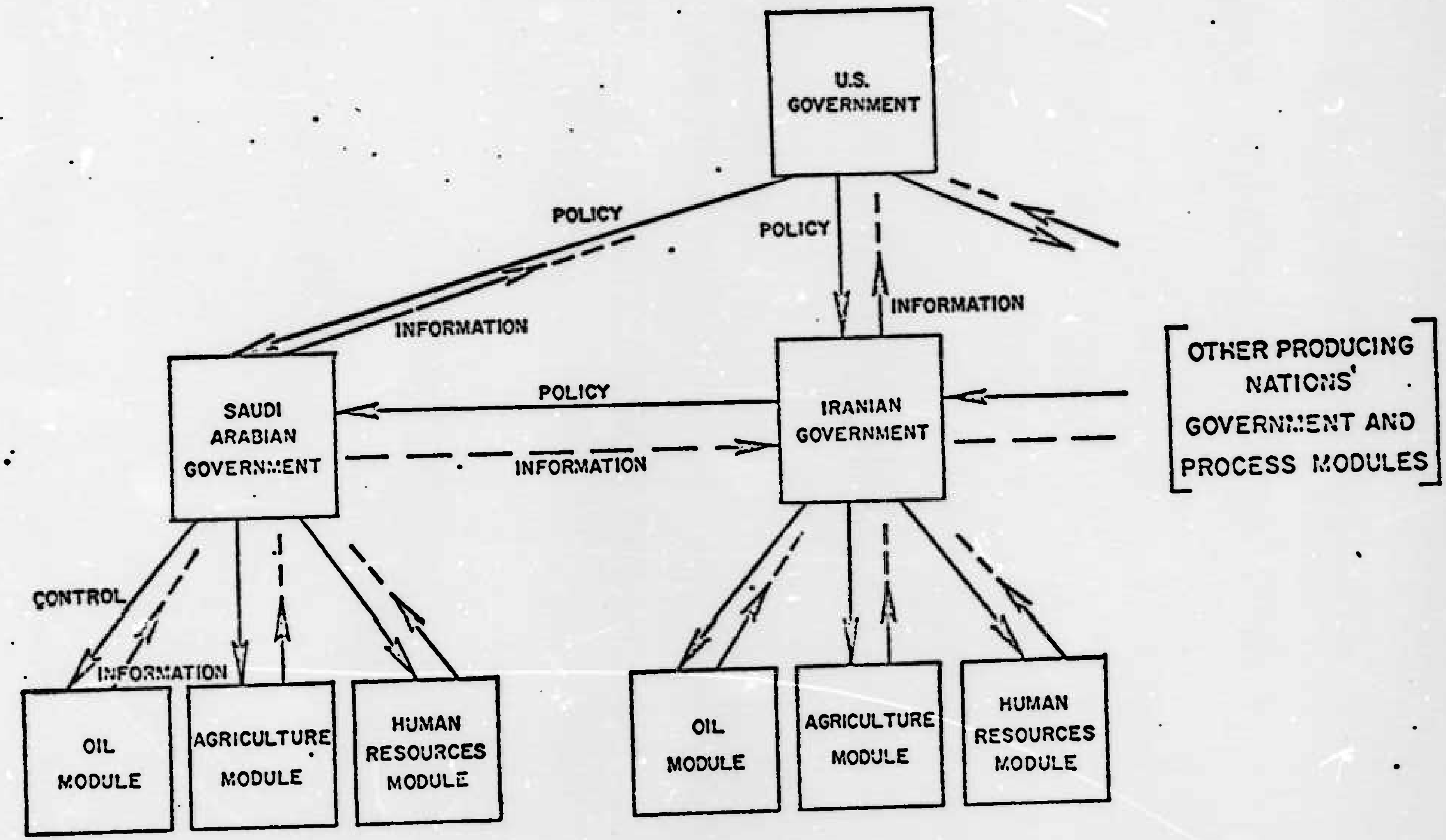


Figure 1.1 Overall Structure of the Simulation

1.2 Summary of Accomplishments During Past Six Months

- Continued work on identifying and programming Decision Module for Saudi Arabia.

- Completed extensive substantive review of the oil, agriculture and human resources modules in conjunction with both policy planners and academic specialists. See PTP Working Paper 38.

- Begun delineation of the roles of analytic and simulation models in policy planning. See PTP Working Papers 33, 34, 35, and 39.

- Continued validation efforts.

- Implemented several of the changes in the simulation modules suggested by the substantive review.

As in previous Semi-Annual Reports, Sections 2 and 3 will summarize technical accomplishments during the past six months. Detailed statements are found in Technical Reports 33-39 (attached). These reports are referenced in the next sections.

2. THE SIMULATION MODULES: STATUS REPORTS

2.1 Introduction. From the perspective of the simulation, the Saudi government is viewed as an information processor which has specifiable goals with respect to its environment. The Saudi government then uses currently available information about present, past, and forecasted future states of the environment to generate policy actions "designed" to increase the level of goal achievement. For the purposes of the simulation, the Saudi government's environment has been divided into two areas - domestic and international. The domestic area has been subdivided into three sectors or "modules" - oil production, agriculture, and human resources. These modules are used within the simulation to generate current information for the government (decision module) and to produce consequences for actions taken by the decision module. At the present, the simulation user will be responsible for providing the dynamics (alternative "scenarios") of the international environment. The Saudi simulation will be prepared to accept a wide range of "international" inputs and to generate a wide range of foreign policy outputs. Figure 2.1 provides a schematic overview of the flow of information in the simulation.

Perhaps the structure of the simulation can best be clarified by a description of an anticipated simulation run. First, the Saudi decision module would receive a set of sentences (information) describing the current state of their external environment. Some of these sentences would be generated by the international environment (i.e., the user) and some of these sentences would be generated by the three sector simulations. The sentences will then be given an interpretation, resulting in a description (on the part of the decision module) of the current state of the environment (this is being termed state knowledge). Next, the decision module would begin to work on the state knowledge and relevant environmental sentences. The Saudi decision module will produce three types of outputs: (1) relevant changes in the state knowledge; (2) authoritative actions on the part of the government; and (3) internal communications. Examples would include budget recommendations such as "increase the budget for fertilizer a lot." These internal communications (or bureaucratic recommendations will then have to be adjudicated, resulting in final authoritative outputs. These outputs would then be channeled to either the international or domestic environments and the next cycle (year, month, etc.) of the simulation would be ready to begin.

Sections 2.2-2.5 will provide a brief, but more detailed, description of the current status of each of the modules. Even more elaborate descriptions are available in the various Technical Reports which have been submitted as appendices to the Semi Annual Reports. These will be referenced as appropriate.

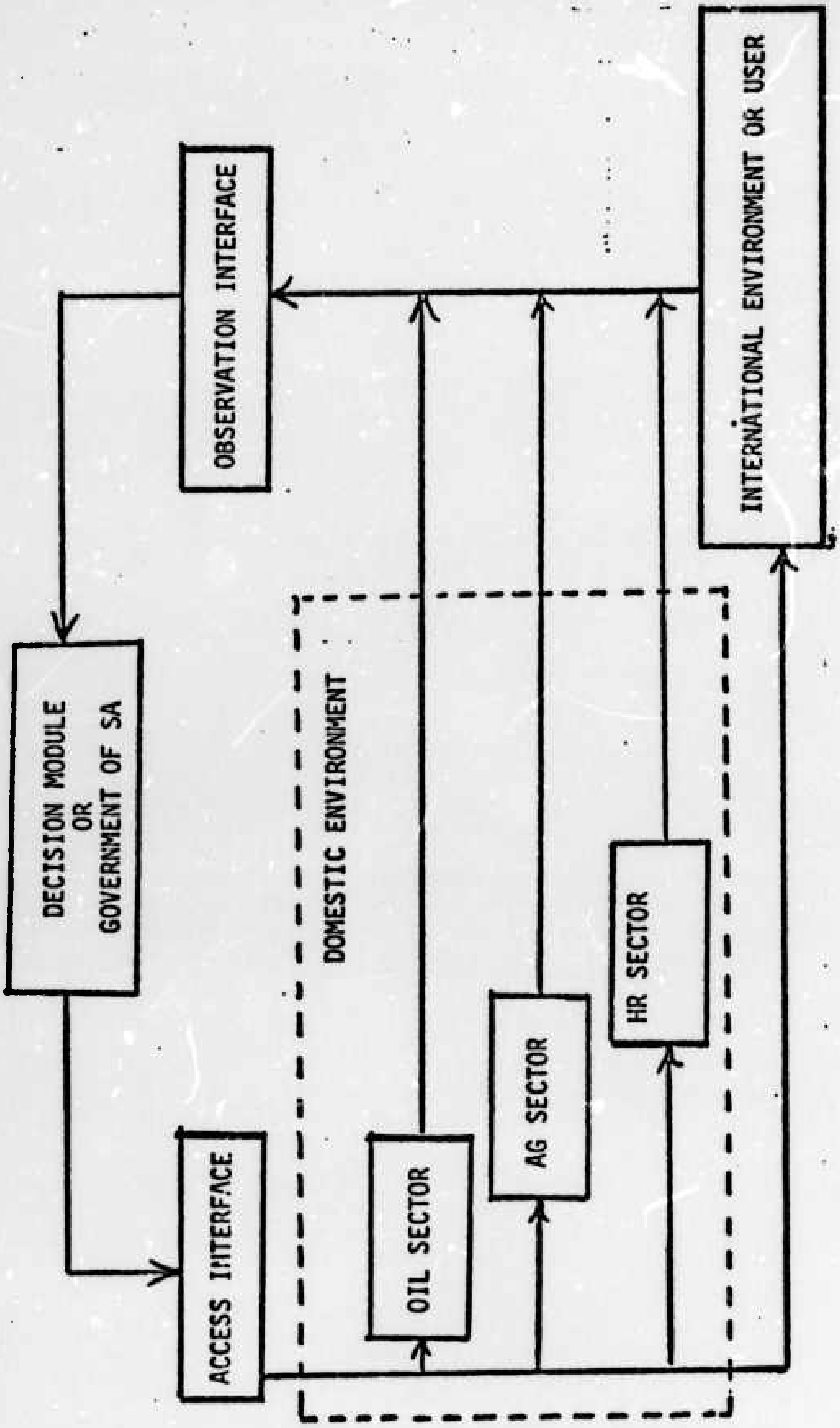

OBSERVATION INTERFACE
INTERNATIONAL ENVIRONMENT OR USER
DECISION MODULE
OR
GOVERNMENT OF SA
DOMESTIC ENVIRONMENT
HR SECTOR
AG SECTOR
OIL SECTOR
ACCESS INTERFACE

FIGURE 2.1

2.2 The Decision Module

Even causal observers of politics are frequently struck with the changing and often apparently adaptive nature of national policy behaviors. International alliances seem to shift in apparent response to changing "realities" such as a perceived scarcity of oil. Yet, as with most all adaptive mechanisms, the range of adaptation has limits. Some policies (U.S. policy towards China would serve as an example) change very slowly and the reason for the slow change seem related more to the international structure of the mechanism itself (e.g., bureaucratic and individual level "politics") than to the external environment the government is attempting to handle.

These observations suggest several principles. First, and of considerable importance, governments must be modeled as control structures operating in specific external environments. That is, governments attempt to manipulate specific external environments. No claim is made that governments are optimal control mechanisms. Further support for this claim can be found in Rosenau, 1970; Rosenau, 1974; and Thorson, 1974a. A well-known example of an attempt to model international behaviors without viewing governments as control structures is found in Forrester, 1971.

Second, the internal structure of the government must be explicitly modeled. In systems terms, the output of the governmental control structure will be a function (in the mathematical sense) of the inputs and the current state of the government. There is considerable evidence to suggest that assessing the state of the governmental structure requires at least the modeling of bureaucratic structures within the government. Empirical support for this claim is found in Allison, 1971; Halperin and Kanter, 1973; and Halperin, 1974. Much of the arms race modeling effort (e.g., Brito, 1972) violates this principle and considers the government as a "unitary rational actor."

Third, internally governments are organized hierarchically. In other words, there is a large degree of specialization within a government. Different kinds of information and decisions are processed at different levels of the hierarchy. Support for this assertion is found in Phillips, 1974; Anderson, 1974; Mesarovic and Pestel, 1974; and Nurmi, 1974. Again, most arms race models and the Forrester WORLD2 model violate this principle.

Fourth, governments pursue multiple (and sometimes conflicting) goals. This principle is related to the previous principle, and support for it can be found in the same sources. While this claim seems most reasonable, there are some technical reasons (Miller and Thorson, 1975b) why this principle may need to be modified. Nonetheless, it has guided the modeling effort thus far.

Fifth, governments exhibit redundancy of potential control. According to Arbib (1972, p. 17) the principle of redundancy of potential control "states, essentially, that command should pass to the region with the most important information." As an illustration Arbib (who attributes the example to Warren McCulloch) cites "a World War I naval fleet where the behavior of the whole fleet is controlled (at least temporarily) by the signals from whichever ship first sights the enemy, the point being that this ship need not be the flagship, in which command normally resides (p. 17)." The critical point here is that potential control need not reside in only one portion of a government. Indeed the way in which various governments resolve the redundancy is critical to understanding and explaining its behavior. Current attempts by the U.S. military to upgrade its command, control, and communications "systems" reflects an implicit recognition of the redundancy notion within one bureaucracy. Moreover, important decisions (e.g., whether to sell a sophisticated weapons system to some country) generally involve more than one bureaucracy at more than one level of the hierarchy. We could find no existing models which have the redundancy property.

Sixth, governments are event-based (that is, governments respond to events in the external environment). These events may have associated with them particular probability distributions. Thus long-range forecasting (though not policy planning) may be very difficult. Moreover the notion of time employed in the model should be "event time," that is, the "time flow" against which the system states are plotted should be event based. This suggests, for example, that differential equation models are either inappropriate or require considerable reinterpretation. The arms race models and the Forrester model are inconsistent with this principle. Crecine, 1969, provides evidence for the event-based nature of governmental structures. See Miller and Thorson, 1975b, for a more detailed discussion of this and the next point.

Seventh, models of governments must allow for disturbances. The environment in which governments operate in noisy, and random disturbances may be important in "defining" the events to which governments respond. The presence of disturbances is especially important to recognize if extremal experiments are to be designed.

The seven principles outlined above serve as framework conditions within which the decision module designed below is being developed. More specifically, two points must be addressed: (1) what are the structural characteristics of a government?; and (2) how is the structure to be implemented as a computer simulation? The first point deals with the nature of that which is simulated. The second, with its realization as a computer program.

The basic characterization used to structure the nature of governments is expressed in one of the organizing principles discussed above: governments are goal seeking systems. But simply to state that governments are goal seeking systems does not provide sufficient structure to allow machine implementation. Additional structure is required. The additional structure imposed upon the characterizations of governments is illustrated in Figure 1. The basic elements of this structure are: (1) the government (or inner environment); (2) the outer environment (the process to be controlled); (3) the observation interface; (4) the access interface; and (5) the model of the outer environment. (Cf. Simon, 1969; Thorson, 1974).

government, with the use of the image of the causal operation of the outer environment, generates outputs (access interface actions) that are intended to increase the level of goal achievement.

In the Saudi Arabian simulation the inner environment, access interface, and observation interface are all parts of the Saudi bureaucracy. The environment can be usefully partitioned into two classes, the domestic and international environments. In the simulation, the domestic environment has been additionally decomposed into three sectors: oil, agriculture, and human resources. Each of these three components are simulations in their own rights. The oil module models oil production and petroleum revenue, the agriculture modules models the production of wheat, and human resources models the flow of people in Saudi Arabia from the perspective of education and employment. Thus, on one level, the decision module attempts to control these three domestic environments so as to achieve a set of goals. In addition, the government of Saudi Arabia has goals for the international environment. The entities in the international environment consists of other nations, e.g., Iran, Egypt, Israel, the United States, the PLO, and the UN, as well as non-governmental actors, e.g., ARAMCO. In this report, the only portion of the simulation to be discussed in any depth will be the agriculture module (the environment) and the portion of the decision module with primary responsibility for controlling it (the Saudi Ministry of Agriculture).

Even with a characterization of that which is to be simulated, and the organizing principles constraining admissible solutions, there is still the question of implementation. Since the construction of the simulation is an effort at elucidating the internal mechanism by which governments generate behaviors, the manner in which the model is represented as a computer program is consequential. The the area of computer simulations of human problem solving, similar concerns have been expressed. Allen Newell (1973a) developed the notion of control structure as a means for addressing this point. The control structure of a model is roughly the system architecture. The control structure specifies how the basic processes of the model are organized into a coherent whole. The control structure is in part determined by the programming language used.

> A language such as FORTRAN (or any other, for that matter) may be seen as a device to evoke a sequence of primitive operations, the exact sequence being conditional upon the data. The primitive operations in FORTRAN are the arithmetic operations, the given functions . . ., the assignment of a value to a variable, the input and output operations, etc. Each of these has a name in the language (+, -, SIN, LOG, etc.). However, just having the names is not enough. Specifying the conditional sequence is also required and what does that is called the control structure. In FORTRAN it includes the syntax of algebraic expressions, . . . the order of statements . . . the syntax of the iteration statement, . . . the format of the conditional and unconditional branch.
> (Newell, 1973b, 297)

For some purposes, it is acceptable to let the programming language determine in large part the control structure. Other times constraints such as minimum execution time, or minimum storage requirements will help determine how the control structure is realized. But if one wishes to make a theoretical statement using the structure of the program itself, those solutions are not acceptable, since such solutions contain implicit but inadmissible theoretical claims. The programming technique (and control structure) that is used for the decision module is called a production system. Since the intent is only to theorize about governments, PL/1 has been used for programming the oil, agriculture, and human resources simulation module. Newell developed this programming structure for the simulation of cognitive processes While the operation of production systems will be discussed in more detail below, several comments are in order. The first is that all operators, other than the basic flow of control in production systems must be explicitly defined. Second, programs structured as production systems do not result in the minimization of program coding time, execution time, or storage requirements. There exist "easier" methods for coding a program to produce similar outputs. But these other ways to program the decision module have the potential for introducing methods and processes that do not reasonably reflect the structure or capability of the processing mechanism of governments. Given the basic flow of control inherent in production systems, it was necessary to define only one additional operator, the ** operator discussed below. This method for structuring the decision module has the advantage that the claims about the information processing capability of governments are explicit. Any assumptions about the capability of governments to process information had to be explicitly defined. Thus the chance of making unintentional capability claims as a result of the way in which the decision module was programmed have been minimized.

Processing models written as production systems are formed by a collection of independent rules, called productions. The rules (or productions) are stated in the form of a condition and an action: $C \rightarrow A$. The condition refers to the symbol in the short-term image (STI) of the system. The STI represents the system's transient image of the current state of the OE. The actions of the productions consists of transformations on the STI "including the generation, interpretation, and satisfaction of goals, modification of existing elements, and addition of new ones." (Klahr, 1973: 528) A production system obeys simple operating rules:

i. The productions are considered in sequence, starting with the first.
ii. Each condition is compared with the current state of knowledge in the system, as represented by the symbols in STI. If all of the elements in a condition can be matched with elements (in any order) in STI, then the condition is satisfied.
iii. If a condition is not satisfied, the next production rule, the ordered list of production rules, is considered.
iv. If a condition is satisfied, the actions to the right of the arrow are taken. Then the production system is reentered from the top (Step i).
v. When a condition is satisfied, all those STI elements that were matched are moved to the front of STI.

vi. Actions can change the state of goals, replace elements, apply operators, or add elements to STI.
vii. The STI is a stack in which a new element appears at the top pushing all else in the stack down one position. Since STI is limited in size, elements may be lost. (from Mahr, 1973: 528-29)

Prior to a discussion of the production system for the Saudi Ministry of Agriculture in detail, the basic operation of the module will be discussed. After the operation of the system has been discussed in a verbal fashion, a portion of the production system will be discussed in detail as a production system.

As discussed above, a number of organizing principles have been employed as constraints on admissible solution to the construction of a simulated government. Not all of those principles are directly reflected in that aspect of the decision module which roughly corresponds to the Saudi Arabian Ministry of Agriculture presented here for several reasons. In particular, the principles of hierarchical organization, redundancy of potential control, and multi-goal seeking are not represented because the simulation module as represented here is only a portion of the total structure. In addition, since the decision module is a developmental version, the decision making properties of the module are at a relatively primitive state. In spite of these shortcomings, the module, as presented above, does serve as a useful illustration of the basic technique and its potential.

In essence, the decision module can be conceptualized as attempting to improve performance as indexed by a function with two arguments yield = f(fertilizer constraint on yield, mechanization constraint on yield). Within the agriculture module, the yield at any given point in time is a function of the level of fertilizer application and mechanization usage. The fertilizer constraint on yield can be expressed as follows: given the current level of fertilization, assuming all other factors are optimal, what is the maximum possible yield? The mechanization constraint has a similar expression. Since the actual yield will be constrained by the smallest constraint, if yield is to be increased, the lesser of the two constraints must be increased. The policy variables open to the government, under this interpretation, are the amount budgeted for governmental fertilizer purchase, and the amount budgeted for governmental provision of tractors.

Assuming that the Saudi's budget is increasing, the motivation for the resultant governmental outputs is as follows: Assume there is more money to spend, the constraint is (say) fertilizer, and the desire is to raise yield. More money should be spend on fertilizer and the same amount of mechanization. Mechanization could be decreased since some money spent on mechanization is wasted, but since it is not known exactly how the mechanization constraint behaves with respect to budget levels and since money is "cheap" and decreased yields are "costly" it is more prudent to take the chance of "wasting" some money by spending more on fertilizer to improve the chance of increasing yield.

From a more operational perspective, it is required that governments make observations of the environment and base outputs upon those "perceptions" of the current state of the outer environment. As a result, inputs into the decision module are statements describing the current mechanization and fertilizer constraints on yield as being very high, high, moderate, low, and very low. These descriptions of the constraints are determined according to the scale in Figure 2.2. An inspection of Figure 2.2 shows the scale not to be an equal interval scale. Judgments between high and very high represent finer distinctions than does a judgment between high and moderate. This scale and the use of an ordinal description of the outer environment is based on two assumptions: the first is that the Saudi government does not have the information processing capacity to handle (nor the measurement sophistication to use) finer distinctions. The second is that the Saudi's are capable of making relatively finer distinctions at the extremes of the scale. This claim about the capability of the Saudi's to process information is supported by Al-Awaji's (1971: 147) description of the planning system as "institutionally fragmented and substantially ineffective," the lack of qualified manpower to staff the Saudi bureaucracy (Al-Awaji, 1971: 218), and the fact that as of today, there still has not been a thorough census of the Saudi population.

Based upon the absolute judgments of the constraints, the decision module makes a comparison between the two constraints, resulting in relative statements such as: "The fertilizer constraint is much greater than the mechanization constraint." This comparison is also based on the scale in Figure 2.2 and reflects the fact that judgments are more fine grained at the extremes of the scale. One constraint is higher than another if a "boundary," i.e., the cutoff point between high and medium is crossed. For example, a very high constraint is judged greater than a high constraint, and a high constraint is judged greater than a medium constraint. If two "boundaries" are crossed, the comparison is that of very high. Thus, a very high constraint is very much greater than a medium constraint, and a medium constraint is very much higher than a very low constraint. If more than two boundaries are crossed, the comparison is 'much greater than.'

These two rankings of the constraints serve as the basic input to the choice portion of the production system. The structure of the decision module breaks the process of generating outputs into two portions. First the budget to be manipulated is determined, e.g., budget for fertilizer purchase, and/or budget for tractor purchase. Secondly, the amount of change in the budget's selected (increase a little, increase, increase a lot) is determined. The decision module uses the first relative judgment (greater than) to determine which budget to manipulate. If one constraint is less than the other, the lowest constraint is chosen. If both constraints are "about the same," both budgets are increased. If the budget to be increased has a high or very high constraint, the budget is increased "a little." If the constraint is medium, the budget (or budgets) is simply "increased." If the level of the constraint is low or very low, the budget is increased "a lot."

In the current implementation of the decision module increase a little means to increase the budget by 20 percent, increase means increase the budget by 50 percent, and increase a lot means to increase the budget by 150 percent. Since the actual budget changes will in the final analysis

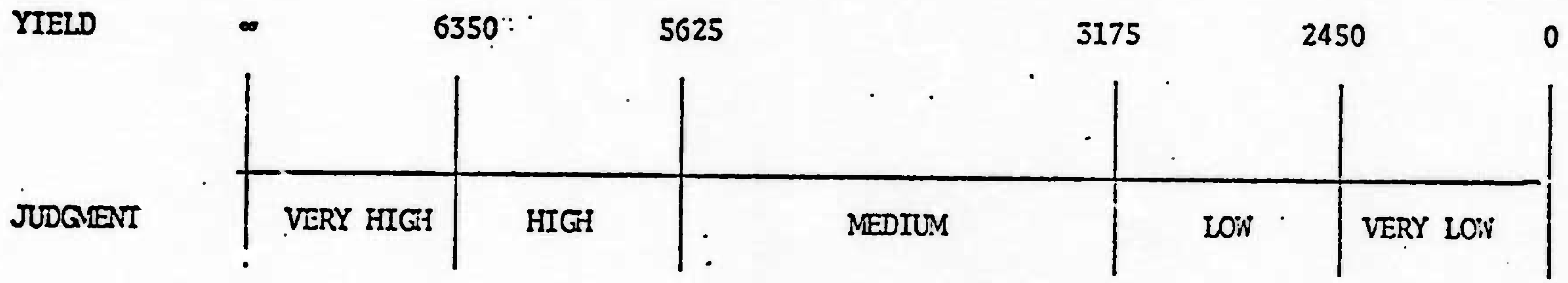

YIELD
∞
6350
5625
3175
2450
0
JUDGMENT
VERY HIGH
HIGH
MEDIUM
LOW
VERY LOW

FIGURE 2.2

be determined by the Council of Ministers, the current procedure represents only a temporary method for allowing a portion of the decision module to operate for testing purposes. The rates of increase should not be taken too seriously. In addition, the portion of the module discussed above assumes no budget decrease takes place.

In light of the above discussion of the rules upon which a production system operates, and the non-technical (from a programming point of view) discussion of the operation of the module, the portion of the agriculture module in Figure 2.3 should be fairly straightforward. The system in Figure 2.3 is that portion of the production system that takes the judgments of the size of the constraints and determines which budgets to increase and by how much they should be increased.

As mentioned above, there is only one operator that was implemented, the ** operator. The ** operator takes the first element in the short term image (STI) and replaces it with the double stars. Thus, if the ** expression were: OLD(**) and the first element in the STI were $$$$$, then after the execution of the **, the front of STI would be: OLD($$$$$). This operator was necessary to insure that the system would not go into an endless loop. If a production were satisfied by the elements of STI, after the operation of the ** operator, the production would not be executed again, until the masked condition were reentered into STI.

As an example, consider the operation when the STI contains the symbols YMECH MEDIUM, YFERT GREATER THAN YMECH. The system starts with production 1. Since the conditions of production 1 are not in STI, the system checks production 2. This process continues until production 12 is executed. The elements in STI match the conditions of the production, and the action portion of the production is executed. This results in (1) the elements in STI that matched the production conditions being placed in front of STI; (2) the ** operator is applied to the first element in STI, YFERT GREATER THAN YMECH. The result is that OLD(YFERT GREATER THAN YMECH) is now the first element in STI; (3) the symbol string INCREASE BMECH A LOT is placed in the front of STI, moving all other symbol strings down one position; (4) control is passed to the first production. The system loops through the productions until none of the productions is satisfied. At that point control passes to the portion of the module responsible for taking these qualitative changes in the budgets and producing actual budget figures.

The agriculture decision module presented here serves only as a preliminary version upon which more sophisticated and reasonable modules can be based. Besides the obvious necessity of addressing the question of validity of the simulations (discussed below), the next path for future development are in two main areas. The first is the development of the processing sophistication of the decision module; for example the necessity to model learning within the bureaucracy. But in its present form, no learning takes place in the decision module. In addition, the implicit model of the environment the module is attempting to control is made up of monotonically increasing functions. For example, the decision module implicitly assumes that the yield function always increases with

FIGURE 2

```
P1  Condition (YMECH ABOUT EQUAL TO YFERT, YMECH LOW)
    Actionn   (OLD (**), INCREASE BMECH A LOT, INCREASE BFERT A LOT)

P2  Condition (YMECH ABOUT EQUAL TO YFERT, YMECH VERY LOW)
    Action    (OLD (**), INCREASE BMECH A LOT, INCREASE BFERT A LOT)

P3  Condition (YMECH ABOUT EQUAL TO YFERT, YMECH HIGH)
    Action    (OLD (**) INCREASE BMECH A LITTLE, INCREASE BFERT A LOT)

P4  Condition (YMECH ABOUT EQUAL TO YFERT, YMECH VERY HIGH)
    Action    (OLD (**),INCREASE BMECH A LITTLE, INCREASE BFERT A LITTLE)

P5  Condition (YMECH GREATER YFERT, YFERT VERY LOW)
    Action    (OLD (**), INCREASE BFERT A LOT)

P6  Condition (YMECH GREATER YFERT, YFERT LOW)
    Action    (OLD (**), INCREASE BFERT A LOT)

P7  Condition (YMECH GREATER YFERT, YMECH HIGH)
    Action    (OLD (**), INCREASE BFERT)

P8  Condition (YFERT GREATER YMECH, YMECH LOW)
    Action    (OLD (**), INCREASE BMECH A LOT)

P9  Condition (YFERT GREATER YMECH, YMECH VERY LOW)
    Action    (OLD (**), INCREASE BMECH A LOT)

P10 Condition (YFERT GREATER YMECH, YFERT HIGH, YMECH MEDIUM)
    Action    (OLD (**), INCREASE BMECH)

P11 Condition (YMECH GREATER YFERT, YMECH MEDIUM, YFERT VERY HIGH)
    Action    (OLD (**), INCREASE BMECH A LOT)

P12 Condition (YFERT GREATER YMECH, YMECH MEDIUM)
    Action    (OLD (**), INCREASE BMECH A LOT)

P13 Condition (YMECH ABOUT EQUAL TO YFERT, YMECH MEDIUM)
    Action    (OLD (**), INCREASE BMECH, INCREASE BFERT)
```

YMECH = Level of mechanization constraint
BMECH = Budget for mechanization
YFERT = Level of the fertilizer constraint
BFERT = Budget for fertilizer

increased levels of the relevant variables. Thus, from the perspective of the decision module, if 2 kilograms of fertilizer per hectare are good, 200000 kilograms of fertilizer will result in even better yields. The second class of sophistication that is planned for the decision module is that of language processing. The quality of language processing becomes especially important when dealing with the international aspects of the outer environment. Diplomacy is in many respects a linguistic exercise. The capability for language processing entails that outputs from the simulation be sentences in a language. For the simulation to have this capability, several things are necessary. First, the language and its associated grammar must be specified. Secondly, the routines must be written which will take sentences describing either states of the environment or actions of other actors as input and produce perceptions of the current level of goal achievement to serve as inputs into the decision making portion of the system.

2.3 Oil Production Module. The oil production module has not been modified in the past six months. Several areas where the oil module requires change (see section 1.6) have been identified and these will be implemented during the next six month period. In addition, programming modifications will be made to integrate this module with the others. At the present time the oil production module is available on a stand-alone basis. It consists of three "stages," each of which represents a specified time period.

The first "stage" is used for the years 1963-1972, and although it makes no attempt to model explicit country-company relationships, it provides values for Saudi Arabia's income from oil revenues for those years. It determines the monthly revenue for any given month of that period by taking one-twelfth of Saudi Arabia's revenue for the appropriate year. The annual revenue figures are taken directly from Table 95 of the OPEC Statistical Bulletin for 1972. The primary purpose of the first stage is to provide revenue data which permit testing other simulation modules over the 1963-1972 time period.

The second stage models country-company relationships for the year 1973. Revenues resulting from the sales of independent and sellback crude are kept distinct from tax and royalty revenues, and the Saudi government's growing control over production capacity, production level, and prices is included in the stage.

The third stage simulates the period beginning January 1974. In this stage, the producing country government sets production levels and prices unilaterally, disregards entirely the Teheran, Geneva I and Geneva II agreements, and determines its own share of participation. It is anticipated that this third stage is flexible enough to permit simulation of various alternate futures through simple changes in its parameters. This third stage represents changes made to reflect recent events.

Research Report Number 23 provides an interim user's manual for the Oil Module in its present stand-along form, and includes examples of needed user input and suggestions for simulation of recent events. Figures 2.4 and 2.5 illustrate the structure of this module.

FIGURE 2.4

Simple Flowchart of Oil Production Module

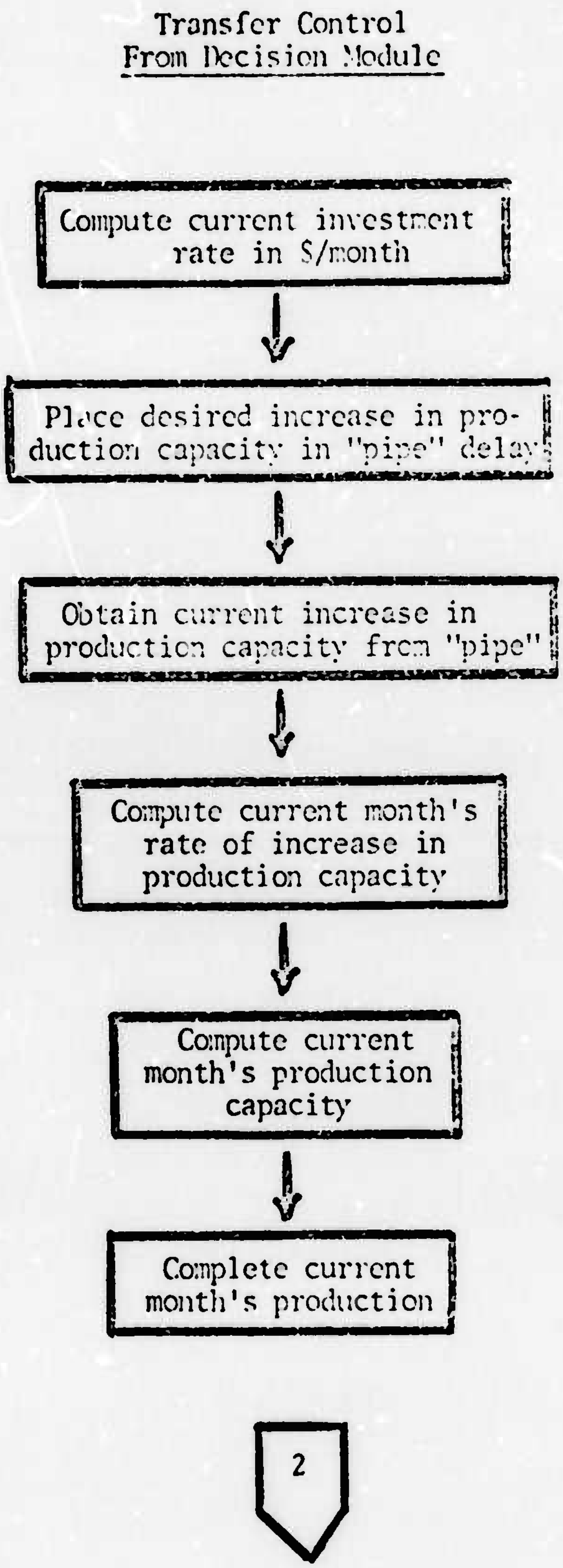


FIGURE 2.4 (cont.)

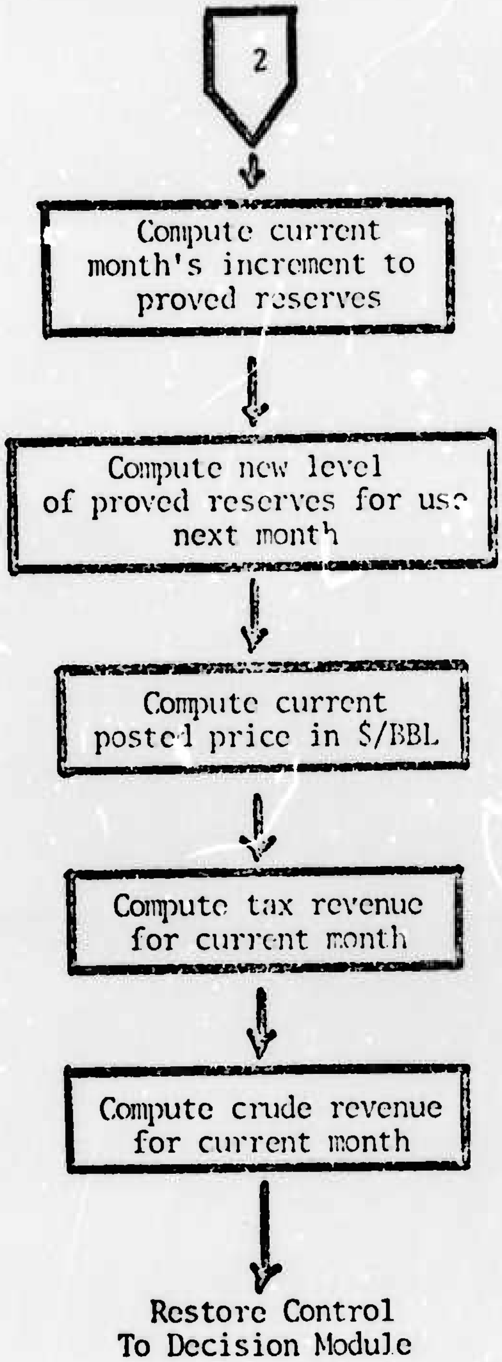
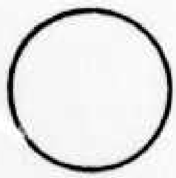
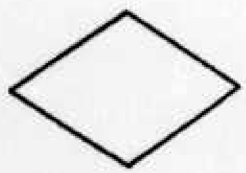


FIGURE 2.4a

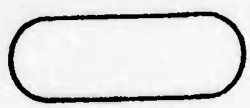
Legend for symbols used in Figure 2.5:



Process information variable

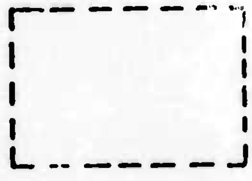


Control information from control stratum



Exogenous information provided by user

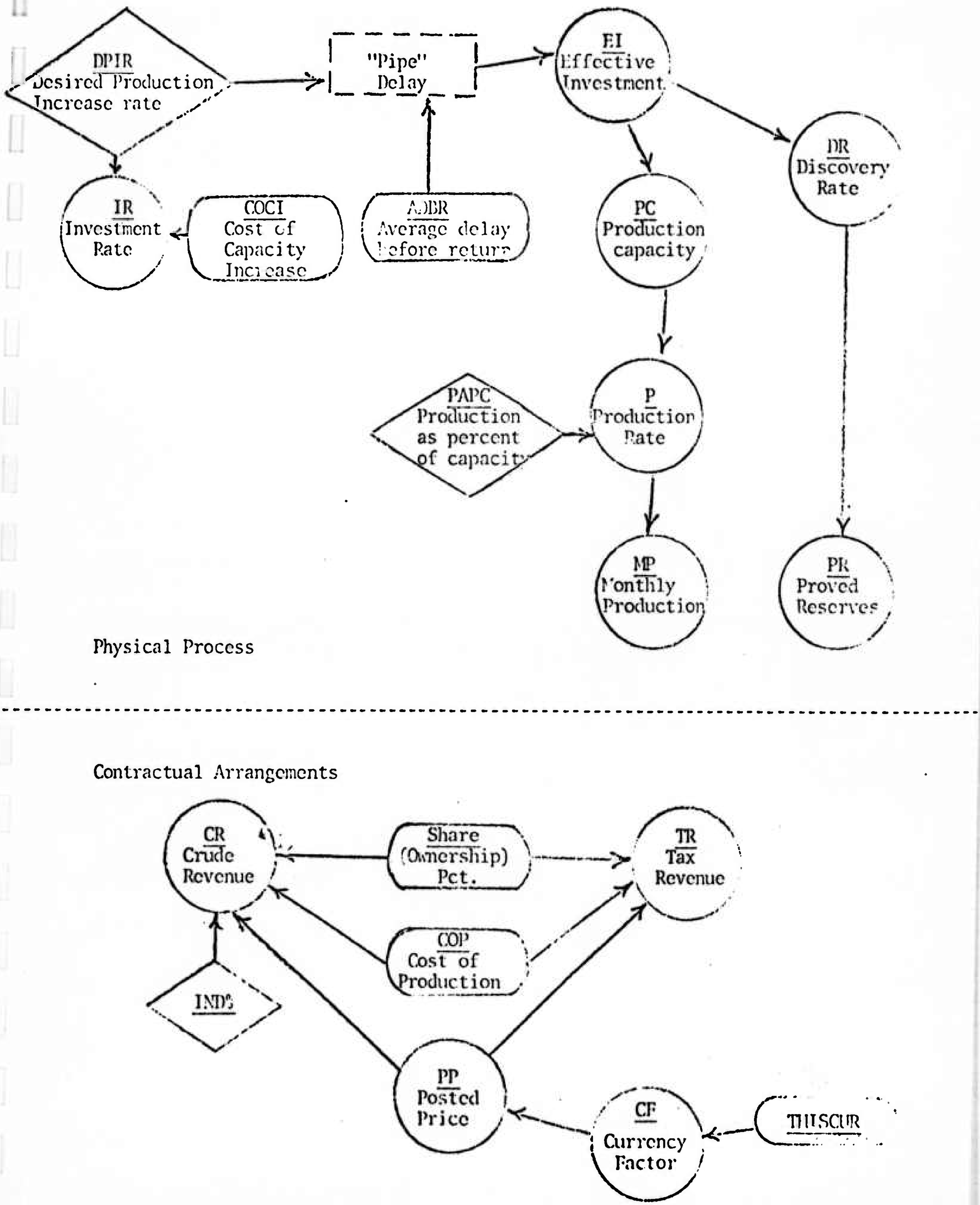
Indicates influence of one variable upon another



Specifics additional detail concerning a particular influence mechanism

FIGURE 2.5

Conceptual Flowchart of Module



2.4 Agriculture Module. While oil is a dominant factor in the economy of Saudi Arabia, the future economic development of Saudi Arabia depends heavily upon the modernization and development of the agricultural sector. The agriculture module (within the simulation) has been constructed in a manner designed to enable the (1) identification and tracing of the various information and material flows in the agricultural production process that influence Saudi decision makers' choices of development policies and programs, and (2) projections of the consequences of various policy choices for agricultural output.

Within the simulation, the couplex array of variables and relations comprising the agricultural sector is conceptually grouped into several sequentially-linked components to simulate various facets of the production process. Four such components are included in the present version of the module: resource allocation, modernization, production, and consumption/demand. The output from each component serves as either an input to another component, an output, or both. The final outputs of the module thus include both physical outputs and performance measures. It is this set of measures which is evaluated by the decision module when choosing policies and programs for the next time period.

The present module is structured to simulate the production of field crops (specifically wheat, the principal crop and food staple). Parameter and initial values have been identified for Saudi Arabia. A summary critique of this module is contained in Section 2.6. Technical Report No. 32 contains a detailed description of this module.

2.5 Human Resources. An important constraint on many possible Saudi policy actions is the availability of personnel with the proper mix of skills. This is especially important considering the Saudi reluctance to use large amounts of foreign manpower. The human resources module is designed to model the development of manpower "pools" in Saudi Arabia. Within the simulation, the population of Saudi Arabia at any one time is divided into a set of mutually exclusive and exhaustive categories. These categories are:

1. unstructured pool (persons about whom there is no available information)
2. persons in elementary school
3. persons in intermediate school
4. persons in secondary school
5. persons in teacher training school
6. persons in technical and adult school
7. persons in universities (both Saudi and non-Saudi)
8. petroleum wage earners
9. non-petroleum wage earners (wage earners in industries and manufacturing other than petroleum)
10. civilian governmental employees
11. military governmental employees
12. non-industrial wage earners (this includes agricultural wage workers)
13. self-employed non-agricultural
14. self-employed agricultural
15. persons no longer active (retirees, deaths, etc.)

These categories were chosen both with respect to availability of data and because they are useful in addressing questions of agricultural, oil, and industrial expansion and contraction.

Persons "flow" from one category to another over a time horizon according to specified transitional constants. For example, a person might move from the intermediate school category to the secondary school category with a probability of .2. A transition matrix containing all these transition probabilities together with a baseline vector of the number of persons in each category is used to generate vector descriptions of Saudi human resources. The transition matrix is, to some extent, open to manipulation by the decision module. As an example, suppose the decision module builds additional schools. Several transition probabilities would be altered. First more people could move from the unstructured pool into elementary education. Also, more individuals might be expected to move to a higher level of education. The precise nature of these manipulations has not yet been determined.

This module is described more fully in Technical Report No. 31. This report also describes the procedures employed in estimating the transition matrix.

2.6 Validation Efforts. The assumptions of the oil production, agriculture, and human resources modules were subjected to a critical review during the past six months. This review was done at CACI, Inc. (see Technical Report No. 38) and was based upon the results of interviews with area experts, ex-flag officers, and policy planners. In this evaluation, two types of criteria were employed. First, there was concern that the module was appropriate for its intended purpose. For example, since the modules are to function as models of processes to be controlled by the decision module, they had to be capable of accepting control inputs which are identifiable as government policies or acting. Second, the module should be consistent with what is believed known about actual causal linkages.

Suggested modifications are summarized below:

A. Oil Module
   1. Increase delay in production capacity increase from three months to six months to two years depending on source of increase.

   2. Introduce equations to describe increase in capital investment necessary to replace depreciated production capital equipment.

   3. Improve estimation of proved reserves by postulating a fixed gross discovery rate.

B. Agriculture Module
   1. The module can safely "largely" ignore the traditional agricultural sector.

   2. Allowance should be made for the "experimental" nature of Saudi agricultural development.

   3. Improve estimates of delay time for new irrigation projects.

   4. Look at geographical distribution of farm equipment.

   5. Demand for wheat should not assume constant income elasticity.

C. Human Resources
   1. Distinguish foreign from domestic labor.

   2. Distinguish students enrolled in religious schools from those in "modern conventional ones."

   3. Modify some parameter and variable values.

These suggestions are presently being examined and a number of them will be implemented during the next six months.

3. DATA

3.1 Data Holdings. Data holdings have not changed substantially in the past six months. Some new data on Saudi human resources has been identified.

4. PERSONNEL

4.1 Principal Investigators. Professor Thorson has been primarily involved with the development of the decision module. He made project related presentations to the International Studies Association, the NSF Conference on Control Theory in International Politics and the Summer Simulation Conference.

Dr. Phillips has continued to devote his time to validation efforts (conducted in interaction with policy planners) and to some work on the decision module.

5. BUDGET

1.	Total amount of contract	\$302,642.00
2.	Funding to date	\$239,169.00
3.	Expenditures and committments to date	\$236,841.00
4.	Estimated funds required to complete contract (1-2)	\$ 63,473.00
5.	Estimated date of completion	June 30, 1976

6. PUBLICATIONS AND WORKING PAPERS

6.1 Publications (No. 17 and 18 new additions this period)

No. 1 Phillips, W. R. and T. Lorimor, "The Effect of Crisis Upon the Stability of the International System," Multivariate Behavioral Research, Vol. 9, October 1974.

No. 2 Phillips, W. R. and R. C. Crain, "Dynamic Foreign Policy Interactions: Reciprocity and Uncertainty in Foreign Policy," The Sage International Yearbook of Foreign Policy Studies, Vol. II, 1974.

No. 3 Phillips, W. R., "Where Have All the Theories Gone?" World Politics January 1974.

No. 4 Phillips, W. R., "Theoretical Approaches in the Events Data Movement," International Interaction, Vol. II (forthcoming).

No. 5 Phillips, W. R., "Forecasting for Planning," Knowledge and Diplomacy: The Interaction of Research and Foreign Policy (forthcoming).

No. 6 Thorson, S. J. and J. Stever, "Classes of Models for Selected Axiomatic Theories of Choice," Journal of Mathematical Psychology, Vol. II, No. 1, February 1974.

No. 7 Thorson, S. J., "National Political Adaptation in a World Environment," Comparing Foreign Policies (Sage, 1974).

No. 8 Thorson, S. J., "Adaptation and Foreign Policy Theory," The Sage International Yearbook of Foreign Policy Studies, Vol. II (Sage, 1975).

No. 9 Wendell, R. and S. J. Thorson, "Some Generalizations of Social Decisions Under Majority Rule," Econometrica, Vol. 42, No. 5 (September 1974).

No. 10 Thorson, S. J., "Problems in Constructing Descriptive, Policy and Design Theories in Foreign Policy Behavior," In Search of Global Patterns (Free Press, forthcoming).

No. 11 Phillips, W. R. and S. J. Thorson, "Simulation for Policy Planning," in the Fifth Annual Pittsburgh Conference Proceedings on Modeling and Simulation (1974).

No. 12 Thorson, S. J., "The Inter-Nation Simulation Project: A Methodological Appraisal" in Quantitative International Politics: An Appraisal (Praeger Publication, forthcoming).

No. 13 Thorson, S. J., "Modeling Control Structures for Complex Social Systems," Interdisciplinary Aspects of General Systems Theory, 1975.

No. 14 Phillips, W. R., "Some Comments on the State of General Systems Theory," Interdisciplinary Aspects of General Systems Theory, 1975.

No. 15 Anderson, P. A., "Role of Complete Processing Models in Theories of Inter-Nation Behavior," to appear in World Studies.

No. 16 Thorson, S. J., "Modelling for Policy Planning," in G. Hilliker (Ed.) Knowledge and Diplomacy: The Interaction of Research and Foreign Policy (O.S.U. Press, forthcoming).

No. 17 Miller, R. A., and S. J. Thorson, "Production Systems as Models of Control Structures for Governmental Decision-Making" to appear in J. Gillespie and D. Zinnes (Eds.) Control Theory and International Relations Research (Praeger Press, forthcoming).

No. 18 Thorson, S. J., P. A. Anderson and E. Thorson, "Governments As Information Processing Systems: A Computer Simulation" to appear in The Proceedings of the 1975 Summer Computer Simulation Conference (forthcoming).

7. PUBLICATIONS AND WORKING PAPERS

7.1 Working Papers (No.'s 33 thru 39 new additions this period)

No. 1. Phillips, W. R., "Theoretical Underpinnings of the Events Data Movement"

No. 2. Phillips, W. R., "Forecasting for Planning"

No. 3. Phillips, W. R., "Dynamic Foreign Policy Interactions"

No. 4. Phillips, W. R. and P. Callahan, "Dynamic Foreign Policy Interactions: Some Implications for a Non-Dyadic World"

No. 5. Phillips, W. R. and M. K. Hainline, "Major Power Conflict Exchanges in the Sixties: A Triadic Analysis of the U. S., Soviet, and Chinese Sub-System from a Comparative Foreign Policy View"

No. 6. Thorson, S. J. and R. E. Wendell, "Location Theory and the Social Sciences"

No. 7. Thorson, S. J. and J. Stever, " Classes of Models for Selected Axiomatic Theories of Choice"

No. 8. Thorson, S. J. and R. E. Wendell, "Some Generalizations of Social Decisions Under Majority Rule"

No. 9. Thorson, S. J. and R. E. Wendell, " A Mathematical Study of Decisions in a Dictatorship"

No. 10. Thorson, S. J., "National Political Adaptation in a World Environment"

No. 11. Thorson, S. J., "Comments on Some Problems in Constructing Descriptive, Policy and Design Theories of Foreign Policy"

No. 12. Phillips, W. R., P. T. Callahan and R. C. Crain, "Simulated Foreign Policy Exchanges: The Rationale Underlying a Theory of Foreign Policy Interaction"

No. 13. Anderson, P. A., "The Decision Module"

No. 14. Callahan, P. T., "An Analysis of the Goals of Five Oil Producing Nations"

No. 15. Crain, R. C., "Oil Module"

No. 16. Hainline, M. K., "Agriculture Sector Module: A Preliminary Sketch"

No. 17. Hermann, C. F., W. R. Phillips, and S. J. Thorson, "Theories and Forecasting in International Relations: The Role of Validation Efforts"

No. 18. Thorson, S. J., "Adaptation and Foreign Policy Theory"

No. 19. Gonzales, C. C., "Military Security Assistance to the Persian Gulf States"

No. 20. Anderson, P. A., "A Discussion of Issues in Need of Resolution: Toward a Specification of the Decision Module"

No. 21. Anderson, P. A. and P. L. Miller, "Why War: A Mathematical Systems Approach"

No. 22. Buss, T. F., "Dimensionality and Spatial Modelling: A Critical Assessment"

No. 23. Crain, R. C., "Interim User's Guide for the Oil Module"

No. 24. Phillips, W. R. and S. J. Thorson, "Simulation for Policy Planning"

No. 25. Thorson, S. J., "The Inter-Nation Simulation Project: A Methodological Appraisal"

No. 26. Anderson, P. A., "Further Discussion of Issues in Need of Resolution: The Notion of a Sentence Writer"

No. 27. Thorson, S. J., "Modeling Control Structures for Complex Social Systems"

No. 28. Anderson, P. A., "The Role of Complete Processing Models in Theories of Inter-Nation Behavior"

No. 29. Phillips, W. R., "Some Comments on the State of General Systems Theory"

No. 30. Buss, T. F., "Toward a Theory of Dimensions for the Social Sciences"

No. 31. Miller, P. L., "Human Resources in Saudi Arabia"

No. 32. Hainline, M. K., and R. C. Crain, "Revised Agricultural Sector Simulation Model for Saudi Arabia"

No. 33. Miller, R. A., and S. J. Thorson, "Optimization and Arms Races: A Model-Theoretic Analysis"

No. 34. Miller, R. A., and S. J. Thorson, "Production Systems as Models of Control Structures for Governmental Decision-Making"

No. 35. Sylvan, D., "Quasi-Experimental Effects of Military Assistance Upon International Conflict and Cooperation"

No. 36. Tamashiro, H., "Goals and Goal-directed Behavior in International Relations"

No. 37. Thorson, S. J., P. A. Anderson, and E. Thorson, "Governments as Information Processing Systems: A Computer Simulation"

No. 38. Phillips, W. R., and R. C. Crain, "Critical Review of the Oil, Agriculture, and Human Resources Modules for Saudi Arabia"

No. 39. Thorson, S. J., and W. R. Phillips, "Modeling for the Future"

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Thorson, S.J. "Modelling Control Structures for Complex Social Systems" in Inter-disciplinary Aspects of General Systems Theory, 1974(a).

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WORKING DRAFT

Optimization and Arms Races: A Model-Theoretic Analysis*

R. A. Miller
Department of Industrial and Systems Engineering
Ohio State University

S. J. Thorson
Polimetrics Laboratory
Department of Political Science
Ohio State University

February, 1975
Research Paper No. 33

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ABSTRACT:

Basic concepts of formal theories and models are reviewed and used for a model theoretic analysis of some of the applications of mathematical methods in theorizing and model construction. The systems theoretic concept of the constructive specification of a model is discussed and optimization, particularly optimal control, approaches to model construction are considered in this light. The results provide a framework in which it is possible to distinguish the analytic requirements of a theory (used to obtain a constructive specification) from substantive requirements. It is argued that a theory can have policy relevance only if the statements of the theory are based on substantive grounds and the model which represents the theory has some established ties with a real system. Since specific results must be specific theory dependent, an analysis of Brito's (1972) paper on dynamic arms races is performed. This paper was selected because it contains a general problem statement and claims policy relevance. It is shown that statements in the Brito theory are included only to meet the requirements of the particular optimal control formulation used. It is also shown that his theory distinguishes between logically equivalent constructive specifications, accepting one and rejecting another.

§ 1 Introduction

As in other areas of social science, international politics theorists are increasingly turning to mathematics for languages in which to express their theories. While examples of specific problem areas which have seen extensive uses of mathematics abound, perhaps the most technically sophisticated are the various extensions to the Richardson analysis of arms races (e.g., Richardson, 1960; Intriligaton, 1964; Brito, 1972; Zinnes and Gillespie, 1973), several of which have analyzed arms races as optimal control problem.

In this paper we adopt a model-theoretic (see §2) perspective to investigate the various roles mathematics might play in problem formulation and theory development and to relate these roles to the various purposes to which the theories might be put. While the argument to be made is general, the specific evidence is specific theory dependent. Therefore much of an analysis will be done on Brito's (1972) paper on dynamic arms races. The Brito formulation was chosen because it is both a very general statement of the arms race problem from the optimal control perspective and is easily accessible. The general conclusions of this analysis are, we believe, applicable beyond the Brito paper. The next section develops the model-theoretic perspective from which we will view the application of optimal control theory to the study of arms races.

§ 2 Varieties of Models and Theories

There are a variety of terms which will be used in a technical sense in developing the argument of this paper. Since these terms (e.g., theory, model, system, etc.) are employed in the international politics literature in a variety of mutually inconsistent ways, it is necessary that some space be devoted to developing rather precise definitions.

The first term to be defined is "theory." Most all uses of "theory" suggest that theories are linguistic, that is they are expressed in some language. In international politics, the language is generally a "natural" one such as Norwegian or English. However, some are expressed in artificial languages such as differential equations (Richardson equations) or DYNAMO (Forrester's World Model). In general, as will be argued below, the language in which a theory is expressed is consequential. Languages are not always interchangeable and propositions which are expressible in one may may not be expressible in another.

Secondly, the sentences in a theory of international politics generally are assertions that some state of affairs obtains in some world; that is, that it is true in some world. For example, one version of Rosenau's adaptation theory contains the sentence "Variations in the structure of a nation are related to changes in the nation's external environment." That the sentences in a theory are asserted to be true world seem to be fairly unobjectionable (for an opposing position see Friedman, 1953). Of course, to assert a sentence to be true does not make it true. Whether particular sentences are accepted as true is largely dependent upon epistemological, methodological, and sociological concerns which are outside the scope of this essay. Truth here is being employed in the sense of Tarski (1944).

Thus far a theory has been said to be a set of sentences each of which is asserted to be true. Since the concern of this paper will be primarily with theories which have some deductive structure relating the sentences, the definition can further be sharpened to read: "A theory, in a technical sense, is a set of sentences where each sentence is asserted to be true and where the set is closed under deduction." That is, the theory set contains any sentence logically implied by any other sentence in the set. Thus, this concept requires some preassigned logical framework such as the predicate calculus. The definition given above is a fairly standard one within the context of the deductive sciences.

In most of the international politics literature, no clear distinction is drawn and maintained between models and theories. Indeed, the common practice is to use "model" and "theory" as synonyms. Thus in some contexts the Richardson equations are termed a "model" of the arms race and in others a "theory" of the arms race. While there is nothing wrong with having synonyms for frequently used words such as "theory," there is a useful technical distinction which can be made between "model" and "theory."

Corresponding to the technical sense of theory defined above, is a technical notion of model where a model for a set of sentences (i.e., a theory) is a set theoretic structure which satisfies those sentences. (This discussion of model is based upon Thorson and Stever, 1974.) More specifically, a set-theoretic structure M is a set of elements (objects), $A = \{a_1, a_2, \ldots\}$ together with a set of relations of order i, $P_1^i 1$, . . ., $P_2^i 2$, and may be expressed

$$M = \langle A; P_1^i 1, P_2^i 2, \ldots, P_n^i n, \ldots \rangle$$

This idea of a set theoretical structure is important to the development of the argument of this paper and will be returned to below. The point to note here, however, is that A is an abstract set (i.e., collection of objects). No particular domain from which the objects must be drawn has been specified. The elements of A could be numbers (a numerical domain), weapons systems (a political domain), words (a linguistic domain) etc. Quite clearly if the goal is to develop a theory which is empirically descriptive of some aspect of politics, e.g., arms races, some of the elements of A should resemble objects believed to be present in the referent reality being theorized about. The relations in M are subsets of i-fold cartesian products on elements in A. Given a set of theoretic structure which is felt to in some (as yet undefined) sense represent the referent reality, the theorist will want to write down sentences which are descriptive of properties of M. These sentences form a theory of M. As an informal example, the arms race work to be considered below appears to be developing a theory of a set theoretic structure where A consists of two nations, each nation's stock of weapons, a consumption stock for each nation, and money. The relations include reaction rules and utility functions for each nation. In order to develop a theory of such a structure, it is necessary to have a language in which the properties of M can be expressed.

Such language L in which properties of M can be expressed will consist of formulas generated by a specified set of rules, say the predicate calculus, from an alphabet consisting of relation symbols (R_1, R_2, . . .), variable symbols (x_1, x_2, . . .), connectives ($\neg, \wedge, \vee$, . . .), and quantifiers, ($\exists, \forall$). Since functions and constants are special kinds of relations, function symbols (f_1, f_2, . . .) and constant sumbols (c_1, c_2, . . .) will also be used in L. The language L is generally assumed to be first order, that is, its variables range over the elements of A (as opposed to ranging over the subsets of A, or set of subsets, etc.). Sentences in L are formulas containing no free variables.

Let T be a set of axioms in a language L. If Ø is a mapping of constant symbols occurring in T into the set of objects A, and also a mapping of relation symbols occurring in T into the set of relations in M, then M provides an interpretation of T under Ø. If this interpretation results in the sentences in T being true, then M is said to satisfy T and M is a model of the axiom set T. A model for a set of axioms then, is a set-theoretic mathematical structure which together with the mapping Ø interprets the axioms in such a way that the axioms are true.

The distinction just made between objects and symbols denoting objects (constants) and between relations and relation symbols should be emphasized. The reason for this distinction is that each mapping onto the objects and relations in a structure M provides an interpretation of the symbols in T. This is important since (as will be shown) a given axiom set can have more than one interesting interpretation, and only some of them will be models of the set.

One of the most obvious problems with the above definition of model is what is meant by a sentence being "true." Rather than provide an extended discussion of truth, the reader is referred to Tarski (1944). The notion of truth being employed here is semantic and not "methodological." The important question is not how we know whether a particular sentence is true but rather what is meant to assert a sentence to be true. Roughly the idea of truth being suggested here is similar to that of Aristotle: "To say of what is that it is not, or of what is not that it is, is false, while to say of what is that it is, or of what is not that it is not, is true." However, a semantic definition of truth views "truth" as a relation between sentences of a language and the objects and relations "referred" to by these sentences.

Thus, in the terms of this paper, truth is structure dependent. That is, sentences which are true of one set-theoretic structure will not in general be true of another.

This "model dependence" of truth is quite important to bear in mind in evaluating mathematical theories of "non-mathematical" phenomena since the Tarski definition of truth is the one generally employed by mathematicians and logicians. One consequence of Tarski's definition is that if some set-theoretic structure together with an appropriate mapping serves as a model for an axiom set, then 1) by definition, the axioms are true of the model and 2) all deductive consequences of the axioms i.e., the theory sentences are true of the model. However, being true of one model does not imply anything about being true of other structures (unless these other structures can be shown to stand in some special relation (e.g., isomorphism) to the model. Thus, for example, great care must be exercised in moving from one structure, e.g., a well specified model, to another, e.g., "the real world." While this point will be developed further below, it will be helpful to first illustrate what is meant by model using several examples.

In order to make this definition of model more clear, consider a very simple Theory T' which contains only two axiom sentences.

A1: $(\ x_1)\ (x_1Rx_1)$

A2: $(\ x_1)(\ x_2)(\ x_3)\ [(x_1Rx_2 \wedge x_2Rx_3) \rightarrow x_1Rx_3]$.

Consider further the following two mathematical structures:

M*: $\langle A;P^2\rangle$ where A is a finite set of "alternatives" and P^2 is the binary relation "is preferred

and

M**: $\langle L;F^2\rangle$ where L is the set of "living males" and F^2 is the binary relation "is the father of."

If the symbol R is mapped onto P^2, and the variables are assumed to range over A, then A1 would read "for all alternatives in the set A, it is never the case that an alternative in A is preferred to itself." Axiom A2 would read: "For any triple of alternatives in the set A, if the first alternative is preferred to the second, and the second is preferred to the third, then the first alternative is preferred to the third." To claim M* to be a model of T' is to assert the truth of these two sentences (A1 and A2). Further, Tarski (1944) shows that asserting a sentence to be true is equivalent to saying it is satisfied by all its objects. Again, there exists no algorithm for determining whether a particular sentence is in fact satisfied by all its objects. However, to assert that T' is modeled by M* is to say that each sentence in T' is satisfied by all its objects.

Let us now examine the relation between the structure M** and the sentences in T'. Do we want to assert that M** is a model of T'? In this case the function maps the relation symbol R onto the relation F^2. Interpreting A1 with M** results in the sentence:

> "For all males in the set of all living males, it is never the case that a male is the father of himself."

To assert that M** is a model for T' is to assert this to be a true sentence. And, indeed, the sentence is empirically true. However, we must be careful not to move hastily from this observation to asserting that M** is a model for T'. The definition of a model requires that all the axioms be true when interpreted by a model. Consider A2. Under M** we have the following sentence:

> "For any three males in L, if male_1 is the father of male_2, and male_2 is the father of male_3, then male_1 is the father of male_3."

Again, to assert M** is a model for T; is to assert the truth of this sentence. Yet this sentence is empirically untrue. Indeed, an ordinary language translation of this sentence would result in the assertion that a grandfather is the father of his grandson. The reason "is preferred to" seems a satisfactory interpretation of R and "is the father of" does not, is that "is preferred to" is generally thought to be a transitive relation (as asserted by A2) and "is the father of" is not transitive. Thus the structure M** is not a model for T'.

Another transitive relation is "is greater than." If the letter "I" denotes the set of integers, and ">" denotes "is greater than," then the structure I,> is a model for T'. A third transitive relation "is greater than or equal to" may be denoted by "$\geq$." Consider whether the structure I,$\geq$ is a model of T'. Clearly axiom A2 is true with this interpretation; however, A1 reads as follows:

> "For any integer, it is never the case that the integer is greater than or equal to itself."

Most of us would assert this sentence to be false and not allow I,$\geq$ as a model for T'.

Hopefully, these simplistic examples provide a general sense of how the terms "model" and theory" are being used in this paper. Moreover, it should be clear from the above discussion that it is possible to develop a theory of models. In Robinson's (1963) words: "Model theory deals with the relations between the properties of sentences or sets of sentences specified in a formal language on one hand, and of the mathematical structures which satisfy these sentences, on the other hand [p.1]."

This notion of model is central to the theory building enterprise.

In theorizing about any phenomena (be it arms races, ethics, or whatever) a necessary first step is to isolate a set of "objects" (variables) with which the theory will be concerned. Each of these objects in turn can take on a number of values. Each of these values is sometimes termed an appearance of the object. For example, suppose some theory of arms races partitioned overall weapons stock into three values or appearances - low, medium, high. From the model theoretic perspective, this means the A component of the mathematical structure $<A; P_j^i>$ will include weapons stock as an object which is itself a set consisting of three elements where each element corresponds to one of the appearances of the object.

Since the arms race work to be examined is based upon systems theory concepts it will be helpful to briefly illustrate the equivalence between a set theoretic structure and an abstract system. In general, theories will not be about phenomena with only one object (e.g., weapons stock) but rather about worlds with "n" objects, X_1 X_2, . . . X_n. A general system can then be defined (Mesarovic, 1968; Windeknecht, 1971) as a relation in the cartesian product of these objects:

$$S \subseteq X_1 \times X_2 \times X_3 \ldots \times X_n$$

The cartesian product of n sets is the set of all ordered n-triples $<x_1, x_2, \ldots x_n>$ where $x_1 \varepsilon X_1$, $x_2 \varepsilon X_2$, . . . $x_n \varepsilon X_n$. A relation on the cartesian product of n sets is simply a subset of all ordered n-tuples. Thus any system is a mathematical structure and may serve as a model for a theory. While this definition is quite abstract, it is possible to get from it to the familiar black box with inputs X and outputs Y. This is done by first defining an index set:

$$I = \{1, 2, \ldots n\}$$

and then partitioning I into

$$I_x = \{i_1, i_2, \ldots i_m\}$$

$$I_y = \{i_{m+1}, i_{m+2}, \ldots i_n\}$$

Since this is a partition,

$$I_x \cup I_y = I$$

and

$$I_x \cap I_y = \emptyset$$

Next define an input set X;

$$X = \{x_i | i \epsilon I_x\}$$

and an output set Y

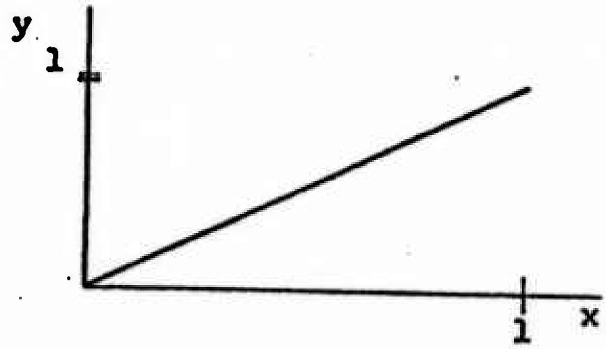
$$Y = \{x_i | i \epsilon I_y\}$$

A system can now be defined as a relation on the cartesian product of inputs and outputs, or:

$$S \subsetneq X \times Y$$

While this may seem excessively abstract, such a view makes it very difficult to fall into the trap of reifying systems. A system is something the theorist imputes on the objects believed to make up the world. If objects are "badly" picked then statements true of the system will not in general be true of the world. That a system can be imputed reflects the constraints on the allowable conjunctions of appearances the objects in the theorists world are allowed to evince.

Thus, the set theoretic system structure considered above is generally at best a statement of existence made by the theorist. The claim is made that some relation on the specified objects does in fact exist. Unfortunately, except for very simple systems one cannot actually specify the system at this level of abstraction. That is, generally it is impossible to write down or otherwise determine which elements of the cartesian product are contained in the subset S and which are not. This should be expected since even in mathematics very few of the objects and relations of interest are specified directly and one of the key problems of mathematics is that of the search for bases or generators for various sets (Hammer, 1971). For example, it is not possible to list all of the elements in $S \subseteq X \times Y$, $X=Y=$set of positive real numbers, even when S is graphically represented by the following figure.



It is possible however to express S in terms of the equation of the line, i.e.,

$$S = \{(x,y) \in X \times Y \mid y=x\}$$

The corresponding task for theorists constructing models of systems is constructive specification (Mesarovic, 1968; Windeknecht, 1971).

The process of constructive specification is very familiar and is probably the cause of much confusion in the modeling process. For example, consider:

$$A = \{1, 2, 3\}$$

$$B = \{2, 3, 4\}$$

$$S = \{(1,2), (2,3), (3,4)\} \subseteq A \times B$$

In this example S is actually a function

$$S: A \to B$$

and clearly

$$(a,b) \in S \leftrightarrow b = a+1, \ a \in A$$

where + refers to ordinary addition of real numbers. This observation allows an alternate description of the set S, that is:

$$S' = \{(a,b)\epsilon A\times B | b=a+1\}$$

S' and S are clearly the same set. That is, S was defined by listing its elements and S' was defined by giving a rule which determined its elements. S' is a constructive specification of S which simply means that the elements in S are determined by a specified formula. Further, it is important to note that the constructive specification is not unique. For example:

$$S'' = \{(a,c)\epsilon A\times C | a=c-3\}$$

where C = {4, 5, 6}, is a different construction but S'' is the same set as S. It should be clear that a large proportion of the sets considered in mathematics are constructively specified.

In the theory proposed by Mesarovic (1968), the constructive specification of a system is achieved through auxiliary functions (to be defined below) and requires the concept of a state representation of S. Any input output system can be written as a relation

$$S \subseteq X\times Y$$

In general the system will in fact be a relation and not a function. That is, there will generally be more than one output element in Y corresponding to a given, unique input in X. A state representation of X provides sufficient additional information about the system to remove this ambiguity and provide for a unique element in Y given the state and the input. Formally this is achieved by representing the given system as the union of several systems each of which is a function in the mathematical sense (unique inputs gives unique output). That is, let

$$\bar{F} = \{f | f:X\to Y \ \& \ f\subset S\}$$

Then, $S = \cup\bar{F}$. It is then possible to define a mapping M,

$$M: \bar{F}\to Z,$$

which associated a unique name with each function in $\bar{F}$. Z is the set of labels or names. Then, the system

$$S_Z: \ Z \times X \to Y$$

can be defined with the property that

$$(z, x, y) \in S_Z \leftrightarrow (z, y) \in S$$

In Mesarovic's terms Z is the global state object of the system and S_Z is the global state representation. Essentially, the state $z \in Z$ defines which function in $\bar{f}$ is used to specify the output $y \in Y$ for a given input $x \in X$.

The state representation removes ambiguity from the system in an abstract sense but it does not necessarily provide any real insight into the system structure. However, a constructive specification sometimes can be developed to provide such insight. Essentially, a constructive specification is a new system S_c which is in some sense simpler than S and can be used to specify the elements of S. It generally takes the form of some type of algorithm. Roughly, the intent is to provide a mechanism by which given the state (an element in Z) and the input (an element in X) the output can be determined.

A constructive specification typically would have the following structure. Mappings

$$\Phi : \ X \to X_c$$

$$\Psi : \ Y_c \to Y$$

are specified and a new system

$$S_c: \ Z \times X_c \to Y_c$$

is determined. To be of use, S_c should be algorithmically determined, i.e., given $z \in Z$ and $x_c \in X_c$ a well defined procedure should exist to determine the corresponding element $y_c \in Y_c$. A constructive specification of S is obtained if:

$$\{(x,y) \in X \times Y \mid y = \Psi(S_c(z, \Phi(x))), \ z \in Z\} \subseteq S$$

We are explicitly assuming the domain of S_Z is the cartesian product $Z \times X$.

As an example of the procedure, consider:

$$S \quad X \times Y$$

$$X = \{x_1, x_2\}, \quad Y = \{y_1, y_2, y_3\}$$

$$S = \{s_1, s_2, s_3, s_4\}$$

where

$$s_1 = (x_1, y_1)$$

$$s_2 = (x_1, y_2)$$

$$s_3 = (x_2, y_2)$$

$$s_4 = (x_2, y_2)$$

A state representation is achieved if we define $Z = \{1, 2\}$ and let

$$S_z = \{(1, x_1, y_1), (1, x_2, y_2), (2, x_1, y_2), (2, x_2, y_2)\}$$

A construction specification of this system is now described. Let

$$X_c = \{1, 2\}, \quad Y_c = \{3, 5, 9\}, \quad Z = \{1, 2\}$$

and let

$$S_c = \{(z, x_c, y_c) | Y_c = z + 2x_c \quad z \varepsilon Z, \quad x_c \varepsilon X_c\}$$

Then, with

$$\Phi = \{(x_1, 1), (x_2, 2)\}$$

$$\Psi = \{(3, y_1), (5, y_2), (9, y_3)\}$$

it follows that

$$S' = \{(x,y) | y = \Psi(z + 2\Phi(x)) \; x \varepsilon X, \; z \varepsilon Z\}$$

and $\quad S' = S.$

Notice that given a state and input, say $z=1$, $x=x_1$, we can "compute" y. That is,

$$x_c = \Phi(x_1) = 1$$

$$y_c = z + 2x_c = 1 + 2 \times 1 = 3$$

$$\Psi(y_c) = \Psi(3) = y_1$$

The conclusion is that $(x_1, y_1) \varepsilon S'$ and hence in S.

It should be explicitly pointed out that the use of numbers and arithmetic in the example is not particularly significant. The importance is that a well defined, well understood set of operations was used to determine the elements which appear in S.

It should also be obvious that there is not much utility in the construction for small finite problems. There is no particular advantage in using the constructive specification of S instead of S itself for such a system. However, in general the system S cannot explicitly be written down and constructive specification provides a way of increasing understanding of the structure of the system.

The concepts of auxiliary functions (Φ, Ψ, S_c) and constructive specification are very common in engineering oriented system theories. In fact as Windeknecht points out [Wind., 1971] they are so common that the basic process and the assumptions are often overlooked. Difference equations, differential equations, stochastic processes, mathematical programming, etc., are all standard models methods used by system engineers and systems theorists. A large portion of the systems theory work tends to be the search for more and more general ways of establishing the properties of the systems of concern.

The results of such efforts are invaluable but certain cautions must be taken. It should be clear that the result of a constructive specification is a system

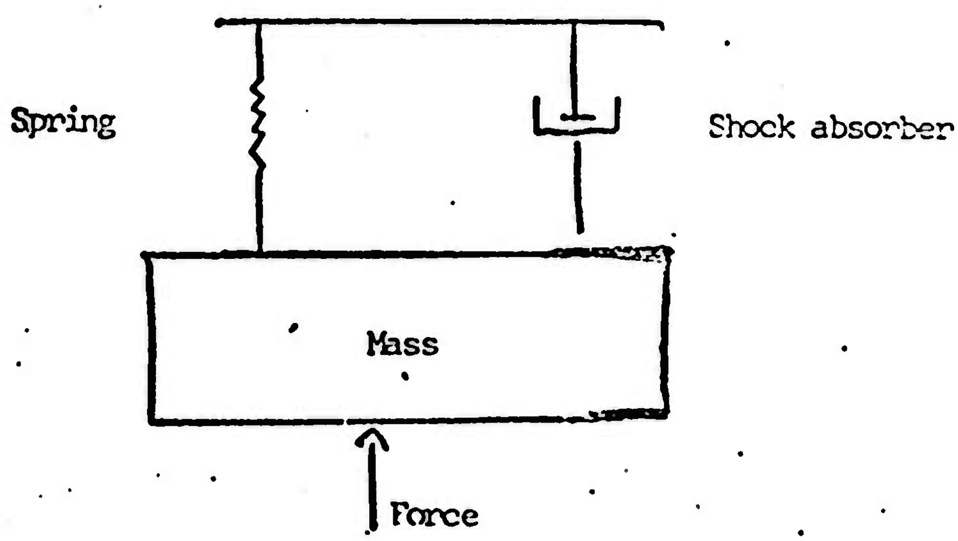
$$S' = \{(x,y)\epsilon X\times Y | y=\Psi(z,\Phi(x)), z\epsilon Z\}$$

It is not within the realm of the constructive specification procedure to establish that $S' \subseteq S$ or even to establish some lesser form of equivalence between the systems.

In many instances the system S is not carefully specified even to the degree of defining the objects. Without a definition of S the mappings Φ and Ψ cannot be defined and by default are implicitly assumed to be identity mappings with $X=X_c$ and $Y=Y_c$. The system model is then the logical result of the specification and nothing more.

Another point can also be made. The global state object defined earlier as well as the global state representation were introduced as mathematical artifacts. Substantive analysis of the system is always required if they are to have any meaning or interpretation. The analyst or theorist is not at liberty to assume a specification procedure and consider his results truth in anything but the system S'.

To better illustrate the point consider an engineering problem of describing the time behavior of the displacement from equilibrium of the mass in the simple mechanical system in the diagram below for various applied forces. It is very reasonable to assume that the diagram accurately reflects the actual interconnections of components in the system.



With forces as a function of time and displacement from equilibrium as a function of time as basic objects an engineer would probably establish mathematical time functions

$$S: T \rightarrow R$$

$$X: T \rightarrow R$$

to describe displacement and force respectively. He would then proceed with a differential equation

$$\frac{md^2x(t)}{dt^2} + \frac{cdx(t)}{dt} + kx(t) = f(t)$$

where m, c, k denote mass, damping constant, and spring constant respectively; x(t) and f(t) are real numbers representing displacement and force at time t respectively, i.e., $t \epsilon T$, $f(t) \epsilon R$, $x(t) \epsilon R$. All numbers are interpreted with respect to established scales of measurement.

The engineer would then use the algorithm (differential equation) to find mathematical functions in X which satisfy the equation for a given function in F representing force. The resulting solutions are his model of the system. The differential equation is his constructive specification.

The point of the example is that the engineer has confidence that his model accurately represents the behavior of the physical system over a specified range of conditions. This confidence arises from an understanding of each component (spring, mass, shock absorber) and confidence in the physical principles used in establishing the behavior of the components when connected in the system. Each part of the model can be justified and interpreted on physical grounds.

If the engineer were asked to construct the same system model without knowledge of the system itself but given several graphs of time histories described as inputs and outputs, he conceivably could obtain the same differential equation using data analytic technique. However, even though the resulting equation and system model is the same as that derived above, the engineer does not have the same degree of understanding of the physical system modeled. In the later case he does not have any interpretation for additional variables brought into the model ($\frac{d^2x}{dt^2}$, $\frac{dx}{dt}$, m, k, c). He furthermore cannot ensure that his model will describe the "real" system behavior for any inputs other than those on which the model derivation was based.

Under the conceptualization developed here, systems based theory building involves theorizing about at least three and sometimes four distinct set theoretic structures. The first, the "referent reality" is not knowable directly and knowledge of it is mediated by perception and cognition as well as measuring devices. Based upon this indirect knowledge, a set of variables and relations is posited (the model, S) and a theory of this model (sentences which are true of it) is developed. If S is a good representation of the referent reality, then the theory will be descriptively useful in making statements about the referent reality. However, often S will be too complex to specify it constructively and to thereby develop useful theories of it. In such cases it is necessary to develop another structure, S', which is constructive and which therefore may permit the development of interesting theory. In the best case, S' will be related to S in the sense that there exists (in the sense of Zeigler, 1971) a behavior preserving morphism from S to S'. That is, S' preserves the input-output relations in S. A theory of S' is useful in making predictions about the behavior of S but will in general not be very helpful in assessing the effect of "reorganizations" of S. Thus, to the extent policy advice concerns other than input changes, S' may not be helpful in giving policy advice even if S is known to correspond well to the "referent reality" and S' preserves input-output relations in S.

Finally, even S' may not be tractable for certain purposes. For examples, if all the inputs and outputs in S' have disturbance terms associated with them, it may be difficult to say certain sorts of things about S'. In such cases a fourth structure S_m may be constructed. S_m might be an optimal control formulation which is reached by further simplifying S'. Again statements true of S_m will not generally be true of S. This is not to say that statements about S_m may not provide insight into S, but only that one should be very wary of using optimization models of the arms race as "...an effective framework within which critical policy issues can be explored (Brito, 1972:374)."

In order to illustrate this last point, it is necessary to consider a particular theory of the arms race. Since the 1972 Brito formulation is one of the most general of the optimization formulations we will again return to it and examine the adequacy of both the theory and the model. Our method will be to critique the model and the theory by demonstrating the questionable and highly implausible statements which the model and theory support. Such an attack is legitimate given the deductive nature of the Brito theory. If this is a theory in the technical sense, then the theory must contain all sentences deducible from the assumptions. The theorist is not free to pick and choose among the deductions those which he wishes to retain and those he wishes thrown out.

§ 3 Construction Specification based on Optimization Methods

As developed, the process has at least three basic parts,

1) a model $S \subseteq X \times Y$

2) a specification

$$\Phi: X \to X_c$$

$$\psi: Y_c \to Y$$

$$S_c: Z \times X_c \to Y_c$$

3) the constructively specified model

$$S' = \{(x,y) \in X \times Y \mid y = \psi(S_c(z, \phi(x))), z \in Z\}$$

The basic system model S is presumably based on substantive analysis of the system and is a model of some theory consistent with empirical evidence. Notice that even in the ideal case when $S' \subseteq S$, the model S' and the model S are only behaviorally equivalent in the sense that input pairs appearing in S' appear in S. There is no requirement that ϕ, ψ or S_c have any particular substantive interpretation. Particularly, one cannot conclude that the artificially produced objects used in the specification actually illuminate the structure of the system S. The best one can say is that S behaves <u>as if</u> it performed the operations used by S_c; one cannot say S performs those operations.

This is particular true of models S' based on optimization procedures. A model specified with optimization notions typically has the following structure. The system model is again

$$S \subseteq X \times Y$$

but the specification assumes the existence of a decision maker who selects the inputs in a particular manner. That is,

$$S_c: Z \times X \to Y$$

and

$$P: S_c \to V$$

are stated, where S_c is the system model and P the performance function which evaluates possible appearances of the system S_c. V is a value set and is partially ordered by some relation, denoted here by $\leq$. We assume $S_c = X$, $Y_c = Y$ for clarity only.

With this structure, it is assumed that the decision maker selects the elements in X corresponding to each state $z \varepsilon Z$ so that

$$P(z,x^*,y^*) \leq P(z,x,y) \ \forall \ x \varepsilon X$$

That is, the decision maker selects inputs x^* corresponding to a given state z which then establishes the output y^*. This appearance of S_c satisfies the partial order relation on V and hence determines which appearances are acceptable. The model S' is then

$$S' = \{(x^*,y^*) \varepsilon X \times Y \mid P(z,x^*,y^*) \leq P(z,x,y) \quad z \varepsilon Z\}$$

Only solutions to the optimization problem are included in the model S'.

Such optimization or maximum principle approaches to model generation are used in Langrangian mechanics in physics for example. The reader is referred to Samuelson (1971) for an excellent discussion of such methods. Again however, the result is a behavioral model, i.e., $S' \subseteq S$ and the optimization itself often does not have any substantive interpretation. It is used only to simplify the specification of the model S'. This can sometimes lead to confusion if the models are to be used for policy analysis and design. This point will be discussed below.

§ 4 Control Systems as Models for Policy Evaluation

The discussions to this point have dealt mainly with the problems of developing descriptive theories and models, that is theories and models which account for observations in the empirical world and identify interrelationships. It is reasonable to assume that policy analysis and synthesis cannot proceed without valid descriptive models. In fact it is often necessary to develop more detailed and structured models consistent with descriptive theories before policy design can be attempted.

The use of control systems and adaptive systems in structures has often been suggested for policy oriented theory development (e.g., see the papers in Rosenau, 1974).

It is important at this point to distinguish between control systems and control problems. Control systems are systems with a particular structure. They are dynamic (parameterized by time), and have input objects that can be partitioned into at least two classes, manipulable inputs and disturbance inputs, i.e., $X=M\times W$ where M denotes manipulable inputs, W denotes disturbance inputs. The system is therefore modeled by

$$S\subseteq M\times W\times Y$$

and each object is a time object (set of time functions). The system has internal mechanisms for determining values for the manipulated variables at each point in time. The mechanism presumably enables the system to achieve desirable configurations and satisfactory overall performance.

A control problem on the other hand is a problem statement that need not have any relationship with a "real" system. Generally, a control problem consists of a system model

$$S_m:Z_m\times M_m\times W_m\to Y_m$$

and performance specifications consisting of the following triple; a performance function

$$P:\ S_m\to V$$

a tolerance function

$$T:\ W_m \rightarrow V$$

and satisficing relation

$$R \subseteq V \times V$$

The terminology is that of Mesarovic (1970). The control problem is considered solved if there is an element in m, say m_s, such that for all elements $z \varepsilon Z'_m \subseteq Z_m$ and $w \varepsilon W'_m \subseteq W_m$

$$(P\ (z, m_s, w, y),\ T(w)\ )\ \varepsilon\ R$$

That is satisfactory performance is achieved for the disturbance set specified assuming the model S_m.

In almost all cases S_m is a constructively specified model and W, M and V are sets with a great deal of mathematical structure. The highly popular optimal control problems require that R be a partial order and T define the minimum (or maximum) element in V for each element in W_m. Essentially then the solution of a control problem is a constructive specification of a model. Whether or not this model is useful for policy analysis depends on the validity of S_m and the interpretations of the performance measures. Such utility is not guaranteed simply because the model derivation followed from a control problem formulation. That is, what is true of S_m need not be true of S unless S and S_m stand in some "known" relation to one another.

For the results to be useful the model S_m must in fact be a good representation of the system S. This most certainly requires that the disturbance set model W_m adequately represent W and not be the result of mathematical convenience. It also requires that predictions made with S_m be in some well defined sense be empirically correct. This fact is clearly recognized by the leaders in the development of optimal control theory, Athans (1971).

Brito (1972) uses an optimal control formulation in his derivation of an arms race model. His overall system involves two nations each of which is modeled in terms of the above structure. Specifically, the following structure is used.

Nation one is modeled by

$$S_{m_1}: W_1 \times C_1 \times Y_1 \to W_1$$
$$P_1 : C_1 \times W_1 \times W_2 \to R$$

and nation two is modeled by

$$S_{m_2}: W_2 \times C_2 \times Y_2 \to W_2$$
$$P_2 : C_2 \times W_1 \times W_2 \to R$$

All of the objects are sets of non-negative real valued time functions and time is modeled by the non-negative reals. Specifically, for each nation

$$S_{m_i}: \{(W_i, C_i, Y_i) | \dot{W}_i(t) = Y_i(t) - C_i(t) - B_i W_i(t), 0 \leq t < \infty\}$$

and

$$P_i = \{(W_1, W_2, C_i, P_i) | P_i = \int_0^\infty e^{-r\,t}(U_1(C_i, D_i(W_1, W_2))\,dt$$

for some real number r, and functions U_i and D_i}

The utility function U_i is not specified but is assumed to have the following properties:

$$\frac{\partial U_i}{\partial C_i}\,[0, D_i(W_1, W_2)] = \infty \qquad W_1, W_2$$

$$\frac{\partial U_i}{\partial D_i}\,[C_i, D_i(0,0)] = K < \infty \quad C_i$$

$$\frac{\partial^2 U_i}{\partial C_i \partial D_i} \geq \quad 0 \qquad C_i, W_1, W_2$$

Also, the functions D_i are assumed to have the following properties:

$$\frac{\partial D_i}{\partial W_i} \geq 0$$

$$\frac{\partial D_i}{\partial W_j} \leq 0$$

$$\frac{\partial^2 D_i}{\partial W_i^2} \leq 0$$

$$\frac{\partial^2 D_i}{\ldots} \geq 0$$

In Brito's formulation C models the consumption level, W weapons stock levels, Y net national product levels. The weapons stock of nation i is the state and output of system i. The manipulated variable in system i is consumption level. The net national product of nation i is an external input to system i and can be considered the input. The weapon level of nation j is an external input and is a disturbance in system i.

Each control problem leads to a constructive specification for each system. That is, a set of solutions can be generated given utility functions and inputs. Specifically, the specification of system 1 is of the form

$$\begin{aligned} S_1' = \{(Y_1, C_1^*, W_1^*) \varepsilon S_{m_1} \mid \\ P_1(W_1^*, W_2, C_1^*) \geq P_1(W_1, W_2, C_1), \\ (W_1, Y_1, C_1) \varepsilon S_{m_1} \text{ and } W_2 \text{ specified}\} \end{aligned}$$

A similar construction holds for system two. Essentially, the specification consists of solutions to the control problem under the assumption that information about the disturbance (other nations weapons stocks) is given.

Brito is interested only in weapons stocks so the overall constructive specification of his system is

$$S' = \{(W_1, W_2) \mid (Y_1, C_1, W_1) \varepsilon S_1' \;\&\; (Y_2, C_2, W_2) \varepsilon S_2'\}$$

It is clear from the above development that the functions which finally appear in the model S' are strongly dependent on the form of the individual system models and the structure of the performance measures. The only justification given for the model is that it is in fact optimal with respect to stated measures of performance and equations of motion. The class of functions defined by S' is broad, but as we will show later it is not necessarily representative of any "real" or even reasonable arms race system.

No control engineer would implement a control law (policy) without first verifying that it does in fact produce satisfactory performance. Typically this is accomplished through testing on a prototype system or when this is not possible through test on a more detailed and more complete model than the model used to design the control law.

In particular, optimality does not imply that the control law is usable. Optimality is always a property of the model but not necessarily of the controlled system. This is why optimal control is useful for space flights where disturbances are minimal and system dynamics well understood but less useful for process control applications where the system dynamics and disturbances are less well understood. In fact, it is no exaggeration to say that no discrete state control system was ever designed with the methods of optimal control theory.

§ 5 Implications

Brito (1972) claims that his model of the arms race provides "an effective framework in which critical policy issues can be explored." He further claims his model proves that "...although the Strategic Arms Limitation Talks may succeed in reaching an agreement to maintain the status quo, neither side will agree to reduce arms levels." These are very strong claims based on a model, in fact on a constructive specification of a model, which is based on very tenuous substantive assumptions.

It is more accurate to state that Brito observed no pairs $(W_1,W_2)\varepsilon S'$, where S' is the constructive specification of his theory, that decreased with time. Clearly, this observation about S' does not imply the same is true in some empirical system modeled by S. In fact no system S is established. It is safe to say that nearly all, if not all, of the statements in the theory are included for the constructive specification process and are not based on observed characteristics of real arms races. For example, the conclusion about non-decreasing weapons stocks is dependent directly upon assumptions about the utility functions involved and these assumptions are at best ad hoc.

It is enlightening to look carefully at some of the requirements of the Brito theory. For mathematical reasons only, "smooth" utility functions are used and marginal utility with respect to weapons is parameterized in the following way,

$$\frac{\partial U_i(C_i,D_i(W_1,W_2)}{\partial W_i} = \frac{\partial U_i}{\partial D_i}\ \frac{\partial D_i}{\partial W_i}$$

Various assumptions are made about the given partial derivaties and this has some interesting consequences.

Assume that nation one has the following utility function

$$U_1(C_1, D_1(W_1, W_2)) = \ln(C_1) + D(W_1, W_2)$$

with

$$D = (W_1 - W_2)^2$$

The utility function is therefore

$$U_1(C_1, W_1, W_2) = \ln(C_1) + (W_1 - W_2)^2$$

This utility function is not allowed by the Brito theory because

$$\frac{\partial^2 D_i}{\partial W_1^{\,2}} = 1 > 0$$

and the theory require that this partial derivative be non-positive.

Now, consider the utility function

$$U_1' \ (C_1,\ D_1(W_1,\ W_2)) = \ln(C_1) + D^2(W_1,\ W_2)$$

$$\text{where } D = W_1 - W_2$$

Clearly,

$$U_1' \ (C_1, D_1(W_1, W_2)) = \ln\ (C_1) + (W_1 - W_2)^2$$

which is identically the same as U_1 defined above. U_1' is allowable under the Brito theory. All derivative conditions on U are met and

$$\frac{\partial D_1}{\partial W_1} = 1 > 0$$

$$\frac{\partial D_1}{\partial W_2} = -1 < 0$$

$$\frac{\partial D_1}{\partial W_1^{\,2}} = 0 \leq 0$$

$$\frac{\partial^2 D}{\partial W_2 \partial W_2} = 0 \geq 0$$

Hence we have one utility function which is accepted by theory under one specification but not another. One would expect an economic theory to be concerned about the utility function but one certainly would not expect the theory to distinguish between alternate writings of the same function. The theory is clearly dependent on the specification and in fact is designed to meet the analytical needs of a particular model. The theory is not internally consistent. Brito's desire to "discriminate between these apparently conflicting viewpoints" of arms race stability is certainly not aided by a theory that cannot recognize the same utility function in two logically equivalent forms.

Claims about policy relevance certainly are not justified. We have been given a new theory and a new model was constructed but this model has no substantive content. We are treated to an exercise in mathematics, not policy analysis.

The sentences in the Brito theory have been shown to have highly implausible deductive consequences. That is, two logically equivalent forms of the utility function are treated differently within the theory. Thus, as a theory of arms races (i.e., of a referent reality consisting in part of weapons stocks, etc.) the Brito theory appears to be unsatisfactory. However it may be that the structure itself, S', is still useful and that the theory simply is an inaccurate description of the properties of S'. To show that this is not the case requires a different form of argument.

Recall that the structure considered by Brito consists of objects such as nations, each nation's stock of weapons and consumer goods, money and of relations such as reaction equations and utility functions for each nation. The question at hand is the extent to which these objects and relations correspond to those of the referent reality in which arms races are believed to take place. The point is not that a model must reproduce all of "reality." Such a position is clearly absurd since such a model would be no less tractable than "reality." However, to deny that models need replicate reality is not to say that any set of objects and relations is acceptable. As Samuelson

(1962) points out in a related context, "If the abstract models contain empirical falsities, we must jettison the models, not gloss over their inadequacies." Similarly, a putative model for a theory of arms races must not ignore without reason objects and relations which appear to be an important aspect of the referent reality. A partial (non-ordered) list of such aspects would probably include time variant utility functions (e.g., in periods of war), arms transfers, disturbance terms, observability problems, differences between decisions to build a particular level of arms and arms actually produced, non homogeniety of weapons systems with regard to threat, cost, deployment, lead time, "depreciation rate," etc., technological innovation, requirements for a nation to consider more than one nation's level of armaments in setting its own, selective targeting, and on and on. None of these seem to be expressible purely in terms of the objects and relations considered by Brito. The purpose of this list is not to suggest that we cannot usefully model arms races. Rather the argument of this paper has been that the modeling approach employed and the interpretation given to any results must be governed by substantive not mathematical concerns. Thus we have shown optimal solutions to be very "brittle" in the sense that their existence and stability is directly tied to the form of the equations used in writing the theory. If the form is chosen for mathematical rather than substantive reasons, then there is no reason to expect that policies which are optimal in S' will also be optimal or even "desirable" in S (especially when S is left unspecified). We simply do not know enough about arms races to embark upon an armaments policy which is based, for instance, upon the difference between differentiable and non differentiable utility functions.

In summary, mathematics provides a wide array of tools which are extremely valuable to international politics theorists both in the area of model specification and in theory development. However, it is important that the specific mathematical tools chosen be chosen for substantive rather than purely mathematical reasons. This is not to say that substantive theory building cannot be greatly aided by having some people posing and solving analytic puzzles which provide insight into various "basic" principles. The recent history of psychology and economics suggests that the posing of such puzzles can be of considerable aid to theory development. However, and this is the point of our paper, such puzzles must not be confused with models for substantive theories. Unfortunately, it may be that as incentives for "policy relevance" increase, the temptation to confuse analytic puzzles with substantive models will become almost irresistable. Yet, as we have shown, much of the power of mathematical argument comes from its ability to identify "non-obvious" implications from explicit assumptions. Many mathematical results - and, in general, solutions to optimization problems - are extremely sensitive to the statement of assumptions. If there is no reason to prefer the precise statement to others which appear "roughly the same" but which do not all permit the existence of an optimum then we should be very cautious about our interpretation of "optimal solutions" in a policy context.

It is not sufficient that mathematical models are valid in the sense that they contain no errors in derivation. They must also be correct in that they be asserted to describe some "real" system. It should serve as a challenge to those who wish to use analytic mathematical structures in policy related problems to develop more robust models and provide explicit ties with substantive models.

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WORKING DRAFT

Production Systems as Models of Control

Structures for Governmental Decision-Making*

Richard A. Miller

Stuart J. Thorson

Ohio State University

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§ 1 INTRODUCTION

Allen Newell (1973a, 290) has observed that there is a common view that "science advances by playing twenty questions with nature. The proper tactic is to frame a general question, hopefully binary, that can be attacked experimentally. Having settled that bits-worth, one can proceed to the next. The policy appears optimal - one never risks much, there is feedback from nature at every step and progress is inevitable. Unfortunately, the questions never seem to be really answered, the strategy does not seem to work." As an alternative Newell suggests developing explicit "complete processing models" of control structures (what we mean by "control structure" will be discussed in § 3,4) capable of exhibiting goal seeking behavior in fairly broad range of task environments. While the particular substantive domain Newell was writing about was experimental psychology, his comments are equally applicable to the field of international politics. Much of the research in international politics is centered around such binary issues as big-small, open-closed, stabilizing-destabilizing, domestic-international, center-periphery and so on. Unfortunately research on these and other binary oppositions has not so far resulted in the sort of general theory of national behavior that many of us would like to see. Perhaps, as is sometimes argued, it is still too early and we must continue rather narrow gauge exercises for a while longer before expecting theoretical payoff - we must move slowly from the simple to the more complex.

However, there are several problems with the "simple to the complex" view. First, the terms "simple" and "complex" are themselves relative to a particular description and it may be that "simple" descriptions of anything as "complex" as the way governments process information to produce behaviors will simply be useless or misleading. Indeed this logical possibility was suggested by Von Neumann (1966,) when he wrote: "There is a good deal in formal logics to indicate that the description of an automaton is simpler than the automaton itself as long as the automaton is not very complicated, but that when you get to high complications, the actual object is simpler than the literary description." In other words, models of governmental control structures may be simpler to construct and exhibit than to describe. If such is the case computer simulation becomes a useful tool.

A second problem with the "simple to complex" position is that it fails to recognize that the simple is interesting only in the context of some (perhaps veiled) picture of the complex. Without a comprehensive view we run the danger of retracing the steps of Sommerhoff's spy who was so obsessed with detail that he followed the telephone cables of the Pentagon to uncover the "true" source of power - and located the Pentagon telephone exchange.

The purpose of this paper is to use a preliminary attempt to model Saudi Arabian decision making to illustrate how control concepts can be useful in developing complete processing models of governments. The Saudi government is viewed as an information processing system. Such systems can be described generally in terms of 1) the goals of the processor 2) the structure of the processor 3) the structure of the outer environment (or specific task environments). The structure of the processor will be modeled by a scheme known as production systems (see § 7). One difference between the approach presented in this paper and most other uses of control theory in international relations is our concern with modeling the internal structure of the processor. While formal reasons for this concern are presented in § 7, a frequently encountered example might serve to illustrate the sense in which we are interested in internal structure.

As a final exam an electrical engineering class is given a sealed black box with three input terminals and two output terminals together with a catalog of electrical components. The exam task is discover the internal "wiring" of the box by observing its behaviors as functions of changes in input signals (probably in the form of electrical impulses). Specifically, they must draw a schematic diagram of the black box mechanism which is complete enough to allow a replica to be built.

To solve the problem, a student must analyze input-output relations to come up with possible mapping functions. However, an input-output analysis is not enough. He must also synthesize and build a mechanism which can actually perform the mappings identified in the analysis. That is, he must model a structure which processes inputs in such a way as to produce the observed outputs. Clearly, not only will any "blueprint" for the mechanism be non-unique, but so will any specification of procedures for moving from the blueprint to an operating realization of the mechanism. Yet, these additional considerations will be of interest to the student of international politics. This process of modeling internal structure might be termed mechanism elucidation (after Fedorov, 1972). It is in this sense that input-output analysis is not enough.

The black box example is, we believe, analogous to the problem of developing theories of the behaviors of governments. Again we must be concerned with the structure which processes information as well as the input-output relations which obtain. Moreover, while we have no "catalog of components" to aid in structural specification, there are a number of observations which, taken together, greatly limit the class of admissible structures. These characteristics of governments will be outlined in the next section.

§ 2 STRUCTURAL CHARACTERISTICS

In modeling governments there appear to be several structural characteristics which any potential complete processing model of a government should exhibit. While each of these principles is fairly simple, taken together there are few existing models which simultaneously satisfy all of them. In this section these principles will be briefly introduced. Succeeding sections will then discuss how control structures might be identified which satisfy them.

First, governments attempt to manipulate specific external environments and therefore if the government is modeled as a control structure, explicit attention must also be paid to modeling the range of environments in which the government operates. Modeling the government as a control structure in no way entails treating it as an optimal controller. A well known attempt to model international behaviors without treating governments as control structures is found in Forrester (1971). In constructing the models of governmental control structures and their environments it is important to explicitly allow for disturbances. The importance of disturbances in the international environment receives implicit support from the ongoing concern over such issues as "accidental way." Disturbances play important roles even in such relatively sophisticated devices as military communications channels. Iklé (1973) cites the example of the Joint Chiefs decision at the beginning of the Six-Day War to order the U.S. ship Liberty into less dangerous waters. The order was sent in at least four different messages over the 13 hour period prior to the Israeli attack. None of the messages was received in time by the Liberty. Two of the messages were misrouted, a third was lost in a relay station, and a fourth was delayed until hours after the attack. "The failure in emergency communications occurred under almost perfect conditions: No facilities had been disabled, there was no enemy jamming and no restrictions on the use of available communication modes (273)." Attempts must be made to model such disturbances.

Second, the internal structure of the government should be modeled. That is, useful models of governments must go beyond preserving input-output relationships to also characterizing the manner in which input information is transformed into outputs. There is considerable evidence to suggest that such an approach requires at least modeling bureaucratic structures within governments (e.g., see Allison, 1971; Halperin, 1974). Such an approach is distinct from, for example, the "unitary rational actor" perspective adopted by most of the arms race modelers. Furthermore, bureaucracies within governments are organized hierarchically. There is considerable specialization within governments and different information and decisions are processed at different points in the hierarchy. This suggests that the control structure will, in some sense, be modeled by a multi-level controller. Further support for this claim can be found in Phillips (1974); Anderson (1974); and Nurmi (1974).

Third, governments pursue multiple (and sometimes conflicting) goals. For example, with respect to the decision to cancel the Skybolt air-to-ground missile, Halperin and Kanter (1973,402) point out "each actor had a different problem and pursued varying objectives." The report on Skybolt by Brandon (1973) suggests that a consideration of these different objectives within both U.S. and U.K. would be required in any descriptive policy study. From a mathematical control perspective, the multiple goals issue poses interesting technical and philosophical issues and §5 is devoted to a discussion of them.

Fourth, governments exhibit redundancy of potential control. According to Arbib (1972, p. 17) the principle of redundancy of potential control "states, essentially, that command should pass to the region with the most important information." As an illustration Arbib (who attributes the example to Warren McCulloch) cites "a World War I naval fleet where the behavior of the whole fleet is controlled (at least temporarily) by the signals from whichever ship first sights the enemy, the point being that this ship need not be the flagship, in which command normally resides (p. 17)." The critical point here is that potential control need not reside in only one portion of a government. Indeed the way in which various governments resolve the redundancy is critical to understanding and explaining its behavior. Current attempts by the U.S. military to upgrade its command, control, and communications "systems" reflects an implicit recognition of the redundancy notion within one bureaucracy. Moreover, important decisions (e.g., whether to sell a sophisticated weapons system to some country) generally involve more than one bureaucracy at more than one level of the hierarchy.

Fifth, governments are event-based (that is, governments respond to events in the external environment). These events may have associated with them particular probability distributions. Moreover, the notion of time employed in the model should be "event time," that is, the "time flow" against which the system states are plotted should be event based. This suggests, for example, that differential equation models are either inappropriate or require considerable reinterpretation. The arms race models and the Forrester model are inconsistent with this principle. Crecine (1969) provides evidence for the event-based nature of governmental structures. The implications of this for specifying time sets in formal control problems are discussed below.

The structural properties just outlined are serving as framework conditions as we attempt to elucidate the mechanisms through which governments process information by modeling to Saudi Arabian decision making with respect to a variety of domestic policy areas. A computer simulation approach has been adopted. The present preliminary version of the Saudi simulation is divided into three external environment modules: an agricultural module, an oil module, and a human resources module. A fourth module, the decision module, serves as a model of the governmental control structure. While our central interest is in modeling the control structure, the first principle mentioned above requires that some attention be paid to modeling the external environment. These simulations are being developed in interaction with policy planners in the U.S. State and Defense Departments (see Phillips and Thorson, 1974, for a description of the interaction). In this paper the focus will be on that portion of the decision module attempting to "control" the agriculture module. However, before getting into a discussion of the specific simulation, it is necessary to state more precisely the claims which have been made thus far and to show how such claims entail a different view of control problems than that generally encountered in international politics.

§ 3 FORMAL MODELS OF CONTROL SYSTEMS

It has been argued that governments can be viewed as control structures operating in specific environments. In this section an abstract formal description of control systems is presented and several structural properties of control systems are detailed. This structure provides the background necessary to distinguish between control systems and control problems and will be used later in the paper to relate production systems and control systems.

Control systems are systems with particular structure. The structure is graphically represented in Figure 1. The basic elements are 1) the inner environment or government or controller; 2) an access interface; 3) the outer environment or the controlled process; 4) an observation interface. Formally the system can be described as an abstract system as follows:

$$S \subseteq IE \times AI \times OE \times OI$$

The system then is a set theoretic relation on the inner environment, the access interface, the outer environment, and the observation interface. Each of these is also an abstract system:

$$IE \subseteq Y \times U$$

$$AI \subseteq U \times M$$

$$OE \subseteq M \times X$$

$$OI \subseteq X \times Y$$

where Y, U, M, X denote the set of possible observations, the set of manipulated inputs or controls, the set of implemented controls, and the set of outer environment responses respectively. Furthermore, the system is dynamic (parameterized by time) which means that the system objects are sets of time functions, i.e.,

$$Y \subseteq A^T$$

$$U \subseteq B^T$$

$$M \subseteq C^T$$

$$X \subseteq D^T$$

where T is a time set and A, B, C, D are the alphabets or sets of possible values for the respective system objects. The superscript notation is used to represent the set of all time functions, e.g.

$$A^T = \{y|y:T \to A\}$$

The alphabets are arbitrary and finite cardinality is possible but not necessary. The time set T is assumed to be, following Windeknecht (1971), an ordered commutative monoid.

The system is further structured by the requirement that it be closed in the sense that

$$s = (y_1, u_1, u_2, m_1, m_2, x_1, x_2, y_2) \in S \leftrightarrow$$
$$y_1=y_2; \quad u_1=u_2; \quad m_1=m_2; \quad x_1=x_2$$

This does not imply that each subsystem is functional (i.e., a mathematical function) but simply requires that the outputs of each subsystem are the inputs of the next.

For purposes of analysis it is customary to place the observation and access interfaces together with either the inner or outer environment. That is, the system can be modeled by

$$\bar{S} \subseteq IE \times \bar{OE}$$

where

$$\bar{OE} = OI \circ (OE \circ AI)$$

where $\circ$ denotes the composition of relations. This in general causes no confusion but some caution must be taken to insure that given data are associated with the appropriate system objects.

In modeling and theorizing about governments the primary object of analysis is the inner environment IE,

$$IE \subseteq Y \times U$$

(or some composition involving the inner environment and the observation and access interfaces.) At this level of abstraction the government is modeled by an ordered pair of time functions, which serve to establish the objects of interest but which cannot provide much descriptive or prescriptive information. If one could be certain that governments were time invariant in an intuitive sense and that off line experiments could be performed to identify the model, such a model might provide such information.

Nevertheless, certain additional properties must be accounted for even at this level of abstraction. The most important property is that the IE subsystem must be a non-anticipatory processor (more precisely a state determined transitional processor, Windeknecht, 1971). Specifically, the inner environment must be decomposible into the composition of a static system and a transitional system,

$$IE = \Phi \circ \Gamma$$

$$\Gamma \subseteq Y \times Z$$

$$\Phi \subseteq Z \times U \quad , \quad Z = E^T$$

for some set E, the state object of OE. Φ must be a static processor (system) which means that for each $t \in T$ the set

$$t\Phi = \{(z(t), u(t)) \in E{\times}B \mid (z,u) \in \Phi\}$$

is a function. Γ is required to be transitional, i.e., the set

$$tr\Gamma = \{(((y_t)^{t'}, z(t)), z(t+t')) \mid (y,z) \in \Gamma \wedge t, t' \in T\}$$

must be a function. $(y_t)^{t'}$ denotes an element in $Y|[t, t+t')$ which is the set of inputs restricted to $[t, t+t')$.

The function $tr\Gamma$ is the state transition function for IE and $t\Phi$ is the output function. These functions are auxilliary functions which can be used to constructively specify the inner environment. In particular this structure guarantees that every output value depends only on previous inputs and the system state.

The representation used above is that of a very general dynamical system. In terms of substantive descriptive modeling issues, the formulation clearly shows the need for identifying the state object, the state transition functions and output functions of the government or inner environment. The emphasis is on the mechanism or process by which inputs from the observation interface are converted to responses and not on the characteristics of these inputs and outputs per se. Clearly however, given the internal structure of the processor, outputs can be generated given inputs, or in other words, if the detailed structure of the system is known its behavior can be predicted. The method by which these structures are to be identified is not established by the abstract structure, but the need for such identification is clearly established.

In summary then, governments are dynamic mechanisms which are presumably "goal-seeking." Goals will provide one way in which the internal structure of the inner environment can be specified. Before examining this issue in greater detail, the technicalities of control problems and goals for control systems will be examined.

§ 4 CONTROL PROBLEMS, OPTIMAL AND SATISFACTORY

The basic structure of the inner environment or controller of a control system was presented in the previous section. There are clearly an infinity of mechanisms that could serve as controllers and which meet the structural requirements. The choice of one mechanism over another depends on the objectives or goals that the system is to achieve. In this section goals are formally modeled with performance measures and other related mathematical apparatus and relationships between mechanism and goals are obtained. Optimal control problems are examined first followed by satisfactory performance problems and multiple goal problems.

Optimal Control Problems

All control problems require additional abstraction beyond that of the general control system model presented in the previous section. Here, an image or model of the external environment (controlled process) is needed. To simplify the development somewhat the access and observation interfaces are composed with the outer environment and the model describes the overall u to y response. In addition, it is convenient in control problems to posit exogenous but non-manipulated inputs or disturbances which influence system behavior. Specifically,

$$OE_m \subseteq U_m \times W_m \times Y_m$$

$$U_m = B_m^{T_1}$$
$$W_m = F_m^{T_1}$$
$$Y_m = A_m^{T_1}$$

A_m, B_m, F_m are model alphabets and T_1 is the model time set. The disturbance set W_m may have physical interpretations as it does in process control applications or it may simply represent model uncertainty, i.e., a mathematical object used to account for deviations between observations and model appearances. The other piece of apparatus needed for an optimal control problem is a performance function

$$P: OE_m \to V$$

where V is a value set partially ordered by some relation denoted here by $\leq$. The performance function evaluates appearances of the model and presumably allows one to pick a best input assuming one exists.

Without loss of generality it can be assumed that OE_m is constructively specified with state transition and output functions. Specifically, assume that

$$OE_m = \Psi o \Omega$$

$$\Psi \subseteq Q_m \times Y_m \quad , \quad Q_m = G^{T_1}$$

$$\Omega \subseteq U_m \times W_m \times Q_m$$

Ψ is static and Ω transitional which implies that for each $t \varepsilon T_1$ the set

$$t\Psi = \{(q(t), y(t)) \varepsilon G \times A_m \mid (q,y) \varepsilon \Psi\}$$

is a function and the set

$$tr\Omega = \{(((u_t)^{t'}, (w_t)^{t'}, q(t)), q(t+t')) \mid (u,w,q) \varepsilon \Omega \wedge t,t' \varepsilon T_1\}$$

is also a function. With these functions it is possible to write the model output as a function of the initial state and intervening inputs. For any $t \varepsilon T_1$

$$y(t) = t\Psi\ (q(t))$$

$$= t\Psi\ (tr\Omega\ (\ (u_o)^t, (w_o)^t, q(o)))$$

The initial time or least element in T_1 is denoted by o. Notice that the initial state may play the same role as a disturbance. Also, if desired it is possible to represent the disturbance as a state determined system but there is little point in doing so here.

The structure of the optimal control problem can now be discussed. An optimal control will in general depend on the specific disturbance input and initial state. Corresponding to each disturbance input, initial state pair consider the set

$$q_o wU^* = \{u^* \varepsilon U_m \mid (u^*,w,y^*) \varepsilon OE_m \wedge$$
$$P(u^*,w,y^*) \leq P(u,w,y) \ \forall \ u \varepsilon U_m \wedge \forall$$
$$t \varepsilon T_1 \quad y^*(t) = t\Psi(tr\Omega((u_o^*)^t, (w_o)^t, q(o)))\}$$

This set is the set of controls which are optimal under the performance function

P for the given disturbance, initial state pair. Clearly, the set $q_o wU^*$ is empty if no optimal solution exists.

As pointed out above there is typically a distinct set of optimal controls for each disturbance input. In most problems of practical interest the control designer must specify a class of disturbances and initial states for which the system is to operate optimally. Label this set $\hat{W}_m$, $\hat{W}_m \subseteq W_m \times G$ and assume that for each element $(w,q_o)\varepsilon\hat{W}$ the set $q_o wU^*$ is obtained. These sets can be used to form a relation which provides the possible optimal controls given the disturbances. That is, the relation

$$U^* = \{((q_o,w),u^*)\ \varepsilon\ \hat{W}_m \times U_m \mid u^*\varepsilon q_o wU^*\}$$

associates a set of controls with each disturbance initial state pair.

Some very important and general observations can be made based on the above description of the optimal control problem solution. First, the solutions are time functions, $u^*\varepsilon U_m = B_m^{T_1}$. Second, obtaining such solutions generally requires clairvoyance since controls are paired with disturbances (which are in general also time functions) by the relation U^*. Third, optimality is judged by the outer environment model OE_m and not by the outer environment itself. Unless there is some guarantee that OE_m is in some sense a valid model, optimality is a useless property (see Miller and Thorson, 1975).

Under certain circumstances, i.e., certain disturbance classes and performance measures, the clairvoyance difficulties may not be so severe. For example, there exists an open loop control $u^*\varepsilon U_m$ which solves the optimal control problem for <u>all</u> disturbance, initial state pairs if and only if

$$\bigcap \{q_o wU^*\} \neq \phi$$

This requires that controls be in some sense independent of the disturbances. Similar conditions can be obtained for certain disturbances with which the optimal control is only a function of the initial state. Clearly, for problems of any substantive interest open loop controls typically will not exist for rich disturbance classes.

Satisfactory Control

Some of the difficulties can be eliminated with the notion of satisfactory performance as proposed by Simon, 1957. A modification of the formalization of Mesarovic, et al, 1970, is used here. Basically, the problem structure is the same as above but a tolerance function and satisfaction relation are included. Particularly,

$$T\colon W_m \times G \to V$$

$$SR \subseteq V \times V$$

Performance is deemed satisfactory if with a control u, given disturbance w, and initial state q_o

$$(P(u,w,y),\ T(w,q_o)) \in SR$$

Notice that V does not have to be ordered to use the satisfaction relation. Typically however V would be ordered by the relation $\leq$ used in the optimization problem. The satisfaction would then define a minimum (or maximum) level so that performance would be deemed acceptable if

$$P(u,w,y) \leq T(w,q_o)$$

For a given performance function, tolerance function and satisficing relation the control problem solution can be expressed in much the same manner as for the optimal control problem. For each element $(w,q_o) \in \hat{W}_m \subseteq W_m \times G$ define the set

$$\begin{aligned} q_o wU = \{u \in U_m \mid & (u,w,y) \in OE_m \\ & \wedge (P(u,w,y),\ T(q_o,w)) \in SR \wedge \\ & \forall t \in T_1 \quad y(t) = t\Psi(tr\ \Omega\ ((u_o)^t,\ (w_o)^t,\ q(o)))\} \end{aligned}$$

The definitio. is very similar to that used for the optimal control, but presumably the tolerance function and satisfaction relation are such that controls are easier to come by. In particular, the tolerance function and satisfaction relation reduce the severity of the clairvoyance problem.

It must be pointed out however that the satisfaction problem as posed here still results in a relation pairing disturbances and controls, i.e., the sets $q_o wU$ can be used to construct the relation

$$U^s = \{((q_o, w), u) \ \varepsilon W_m \times U_m \mid u \varepsilon q_o wU\}$$

Selection of a control requires knowledge of initial state and disturbance, but presumably a given control solves the control problem for a class of disturbances.

Tolerance functions and satisficing relations are often introduced implicitly. For example, if design is based on a "typical" disturbance $\bar{w}$, a control which optimizes performance for this disturbance is found. Optimal performance will not necessarily be achieved for other disturbances and a range of performance is possible depending on the possible disturbances. This range essentially defines the satisficing relation in $V \times V$.

The same is true of probabilistic methods. If a control is selected to minimize the expected performance, a range of performance is again possible depending on disturbances. A design which determines a control to keep the performance value within a specified region with some probability is explicitly using a tolerance - satisfaction approach.

The basic problem with both the optimal control and satisfactory control results of this section is their structure. They are time functions and not processors or systems. This resulted because of the structure of the control problem formulation. In section §6 the realization problem and duality between mechanism and goal is examined. This will provide the tie between the descriptive results of the previous section and the control problem results of this section. First, the problem of multiple goals is briefly considered.

§ 5 MULTIPLE GOALS

It is generally recognized that governments are multiple goal organizations but it is quite difficult to establish what this statement means in any but an intuitive way. In defining and modeling governments as control mechanisms however, it is important to have a precise formulation of what is meant by multiple goals. One such structure is provided in this section.

The same overall macro view of the outer environment of a government that was used in the previous section is again used here. The same state determined model of the outer environment that was used in the previous section is again assumed.

For purposes of discussion here, a multiple goal control problem is one in which there are several performance measures of interest for the system. That is, there are say k distinct functions which evaluate system performance:

$$P_i : OE_m \rightarrow V_i \qquad 1 \leq i \leq k$$

The value sets need not be identical. It is assumed however that for each i there is a relation R_i which partially orders V_i.

Two comments about this structure are in order. First, we do not assume the existence of an explicit aggregate performance function, i.e., a function (or even a class of functions) of the form

$$\bar{P}: \ P_1 \times P_2 \times \ldots . \ P_k \rightarrow \bar{V}$$

is not assumed. The reason for this assumption is that such an aggregate, single valued performance function reduces the problem to the single performance measure problem discussed in the previous section. It seems unreasonable to impose this additional structure at the outset although it perhaps is necessary for algorithm development. The second comment deals with the relationship between the structure of the process model and the structure of individual performance measures. The system model is multi dimensional involving control inputs, disturbances, and outputs or outcomes. The performance function is assumed to map system appearances, as represented by the model, to some value set. Each performance function can therefore provide tradeoffs between the various system objects and each performance function represents one such trade-off evaluation. For purposes of discussion here, multiple goal situations refer to cases in which the designer or decision-maker or controller has several methods of evaluating performance.

Multiple goal or multiple objective problems have not received a great deal of attention in the control theory literature. The mathematical programming literature provides some results under the label of multiple objective programming and goal programming but these typically deal with ways of combining or aggregating individual measures (Cochrane and Zeleny, 1973). Some recent methods however allow significant interaction with the decision maker (Geoffrion et al, 1967). All of these results however deal with problems that have a great deal more mathematical structure than has been imposed here. Given that the issue is concept development it is undesirable to let such methods dictate problem formulation.

It seems that a more general and less constraining view of multiple goal than that provided by the mathematical programming literature is that provided by a generalization of the satisfaction notion of the previous section. Assume that corresponding to each performance function a tolerance function is also defined. That is,

$$T_i: \; W_m \times G \rightarrow V_i$$

A satisfaction relation is then a relation of the form

$$SR \subseteq V_1 \times V_1 \times V_2 \times V_2 \times \ldots \times V_k \times V_k$$

Given an appearance of the system model, $s=(u,w,y)$ corresponding to the disturbance w and some initial state q_o, the control u is satisfactory if

$$((P_1(s),T_1(w,q_o)),\ (P_2(s),T_2(w,q_o)),\ \ldots\ (P_R(s),T_R(w,q_o)))\ \varepsilon\ SR.$$

The problem is certainly more complex than a single goal problem, but certain features are unchanged. Satisfactory controls are still tied to disturbance functions and initial states. The satisfaction relation essentially allows representation of the problem in terms of constraints. It is rich enough to include ordering or ranking of objective functions (through choice of individual tolerance functions), it includes as a special case situations in which certain performance functions are optimized (again through choice of individual tolerance functions). No method is provided for defining overall system performance and hence satisfactory solutions cannot be ranked except on individual performance dimensions.

The point of the discussion however is that with single or multiple goals, satisfaction or optimality, the control problems as posed always lead to a relation of the form

$$U^s = \{((q_o,w),u) \in \hat{W}_m \times U_m \mid u \in q_o wJ\}$$

where $q_o wJ$ is the set of controls which achieve satisfactory performance given the initial state q_o and disturbance w. Multiple goals presumably increase the difficulty of the technical problem of finding solutions and satisfaction measures reduce somewhat the information requirements, but neither changes the basic mathematical structure of the solution. Also, this structure in its present form cannot be used to directly describe governments. Performance functions even with good outer environment models, do not lead directly to models of government. The reason, as will be shown in the next section, is very similar to the reason why solutions of optimal control problems do not necessarily lead to solutions of control system design problems.

§ 6 STATE DECOMPOSITION OF A CONTROL PROBLEM SOLUTION

The results of the previous two sections show that the solutions of control problems are mathematical relations establishing control trajectories in terms of disturbance trajectories. The problem of interest in this section is that of constructing a processor to realize the control inputs in a transitional manner using only available information. In the process relationships between performance requirements and mechanism or processer descriptions of the controller are developed.

The first step is to develop a model of the inner environment to realize the controls with respect to the model of the outer environment model. Recall that the satisfaction or optimal control problems provide, assuming solutions exist, a relation

$$U^S = \{((q_o,w),u) \in (G\times W_m)\times U_m \mid u\in q_o wU\}$$

That is corresponding to each initial state and disturbance there is at least one control which solves the control problem based on an outer environment model,

$$OE_m: \; G\times W_m \times U_m \to Y_m$$

This description of the outer environment model is an initial state representation which clearly follows from the state decomposition model used earlier.

From OE_m it follows that for each control $u\in U^S$ there is a corresponding outcome y. Therefore, appearances of OE_m using optimal or satisfactory controls can be written

$$OE^*_m = \{(q_o,w,u,y) \in G\times W_m\times U_m\times Y_m \mid (q_o,w,u) \in U^S \wedge (q_o,w,u,y) \in OE_m\}$$

OE^*_m is that subset of OE_m which results when non-satisfactory controls are excluded. A general processor model of the inner environment then follows immediately,

$$IE_m = \{(y,u)\in Y_m\times U_m \mid \exists\, (q_o,w): \; (q_o,w,u,y)\in OE^*_m\}$$

This model is the general dynamical system or processor which solves the control problem for the given outer environment model.

Results of Windeknecht (1971) are now used to provide a state decomposition of IE_m. Define

$$u_t = \{(\tau, u(t+\tau)) \mid \tau\epsilon T_1\}$$

and for each $u\epsilon IE_m^2$, where

$$IE_m^2 = \{u \mid (y,u) \ \epsilon \ IE_m\}$$

associate the set

$$Fut\ u = \{(t,u_t) \mid t\epsilon T_1\}$$

u_t is a left translation of the function u and is itself a time function. Fut u is the set of appearances of translation of the input u at all times $t\epsilon T_1$. A state decomposition of the inner environment is provided using these sets.

Let

$$\Gamma_m = \{(y, Fut\ u) \mid (y,u) \ \epsilon \ IE_m\}$$

$$\Phi_m = \{(Fut\ u, u) \mid u\epsilon IE_m^2\}$$

Clearly

$$IE_m = \Phi_m \circ \Gamma_m$$

The transition function of Γ_m is

$$tr\Gamma_m = \{(((y_t)^{t'}, (Fut\ u)(t)), (Fut\ u)(t+t')) \mid (y,u)\epsilon IE_m \wedge t,t'\epsilon T_1\}$$

Careful examination will show that

$$(Fut\ u)(t) = u_t$$

That is, (Fut u)(t) is Fut u evaluated at t and is the left translation of u corresponding to time t. Therefore,

$$tr\Gamma_m = \{(((y_t)^{t'}, u_t), u_{t+t'}) \mid (y,u)\epsilon IE_m \wedge t,t'\epsilon T_1\}$$

To see that tr Γ_m is a function, assume that $(((y_t)^{t'}, u_t), u_{t+t'}) \ \epsilon$ tr Γ_m and

$$(((z_\tau)^{\tau'}, v_\tau), v_{\tau+\tau'}) \ \epsilon tr\Gamma_m$$

Then, if $(y_t)^{t'} = (z_\tau)^{\tau'}$ it follows that the time shift is the same. Thus, if $u_t = v_\tau$ then common time shift implies

$$(u_t)_{t'} = (v_\tau)_{\tau'} \rightarrow$$

$$u_{t+t'} = v_{\tau+\tau'}$$

which proves that tr Γ_m is a function.

Φ_m is a uniformly static function. That is, the attainable space of Φ_m is

$$\alpha\Phi_m = \{(\text{Fut } u)(t), u(t)) \mid u\varepsilon IE_m^2 \wedge t\varepsilon T_1\}$$
$$= \{(u_t, u(t)) \mid u\varepsilon IE_m^2 \wedge t\varepsilon T_1\}$$

$\alpha\Phi_m$ is a function since

$$(z_\tau, z(\tau)) \varepsilon \alpha\Phi_m$$
$$(u_t, u(t)) \varepsilon \alpha\Phi_m$$

and $z_\tau = u_t \rightarrow z_\tau(o) = u_t(o) \rightarrow z(\tau+o) = u(t+o) \rightarrow$
$z(\tau) = u(t)$.

The conclusion is that Γ_m and Φ_m provide a state decomposition of the inner environment model. Furthermore, the set

$$\overline{IE}_m^2 = \{u_t \mid u\varepsilon IE_m^2 \wedge t\varepsilon T_1\}$$

is a state space for the inner environment model, the set of initial states is IE_m^2 and the set of state trajectories is $\{\text{Fut } u \mid u\varepsilon IE_m^2\} = \Gamma_m^2$

The above proves the existence of a state decomposition of the inner environment model. In practice it is not necessary to work with the above decomposition and a more convenient state representation can be obtained and used. The representation presented above is however the smallest (in the sense of the cardinality of the set of state trajectories) state decomposition that can be used. The interested reader is referred to Windeknecht (1971) for more details.

It is important to fully understand the significance of these results. In order to facilitate the discussion an equivalent state decomposition is used. Consider a one-one, onto function f,

$$f: \Gamma_m^2 \rightarrow Z_m \quad , Z_m \subseteq E_m^{T_1}$$

and let

$$\gamma_m = \Gamma_m \circ f$$
$$\phi_m = \Phi_m \circ f^{-1}$$

Then, $\phi_m \subset Z_m \times U_m$

$\gamma_m \subset Y_m \times Z_m$

and $IE_m = \phi_m \circ \gamma_m$

Hence, ϕ_m and γ_m are another state decomposition of IE_m. This change does not alter the substance of the problem at all, but allows us to use labels or indices for the states.

The behavior of the state realized model of the inner environment can now be examined. Using the state decomposition it follows that for any time $t \varepsilon T_1$,

$$u(t) = a\phi_m(tr((y_o)^t, z_o)$$

where $a\phi_m$ denotes the attainable set of ϕ_m,

$$a\phi_m = \{(z(t), u(t)) | (z, u) \varepsilon \phi_m \wedge t \varepsilon T_1\}$$

The function which defines u can be interpreted as a control law or policy. That is, it is a rule which is used to map information to all control actions. At present it is a policy which applies only to the model of the outer environment, not the outer environment itself.

This control law has some very interesting features however. First, it is designed to operate only as those elements of Y_m that are outputs in OE_m^*. It is entirely possible that there exist outputs in Y_m (corresponding to disturbances not considered) that cannot be processed by the controller, i.e., the state transitions are not defined for such inputs. Second, corresponding to each controller initial state is a family of control trajectories each member a function of the response obtained and hence dependent on the disturbance. The problem of how the controller gets into a particular initial state is not answered by the state decomposition method. The method simply says that given initial state and the observation trajectory, control trajectories can be computed. In a sense, one problem has been replaced by another. Selection of a control trajectory required clairvoyance, initialization of the controller requires knowledge of the proper initial state and hence clairvoyance. That is, there is no apriori guarantee that performance is satisfactory if the controller starts in any but the correct initial state or set of states.

Fortunately, things are not as bad as they first seem although there can be difficulty if optimal performance is insisted upon. There is a wide class of problems which meet the conditions imposed - control engineers would be out of business otherwise. Satisfactory performance plays an important role here.

Static controllers is one class which does not have initial condition problems. With a static controller only the current observation value is needed to compute the control, i.e., the set

$$tIE_m = \{(y(t), u(t) | (y, u) \varepsilon IE_m \wedge t\varepsilon T_1\}$$

is a function. The state of the controller at time t is y(t) and the control is computed with tIE_m. The widely studied linear-quadratic regulator problem of optimal control theory falls in this class if complete state measurements are available (Athans & Falb, 1966).

Stochastic regulators and observers however do suffer from the problem in the sense that the controller initial conditions must be properly set for performance to be optimal (Bryson & Ho, 1969 ; Miller, 1973).

Satisfactory performance plays an important role at this point. Essentially, the role of the tolerance function and satisfaction relation is to enrich the set of acceptable controls in a control problem. If the set U^S is a relation and not a function, then the satisfactory control corresponding to a given disturbance is not unique. Recall that U^S was defined in the previous section and relates disturbances with acceptable controls. If U^S is in some sense large enough that all controller initial conditions produce control trajectories in output set of

U^S the problem is eliminated. One way to guarantee this is to restrict the problem to selecting mechanisms. That is, a class of controllers (state transition functions and controller output functions) are posited and the design objective is to select one of these mechanisms. This is precisely the procedure followed in most classical control theory and it is the way most control engineering work proceeds.

The view expressed above is the technical design view. Given that governments are operating systems, a more appropriate view is that of the evolution of the process or system. Loosely speaking this reflects a concern about what the system itself looks like at time t rather than a concern about the particular appearance of the system. The initial state issue is of less concern in this view and adaptation concepts take on an important role. This concept will not be pursued further in this paper.

The conclusion to be drawn from this section is clear. There is a very strong relationship between control problem solutions and the mechanisms which are used to realize control systems. The performance requirements reflected through performance functions, tolerance functions and satisfaction relations together with an outer environment model place constraints on acceptable controller behavior. These constraints are directly reflected in the state space and state decomposition used to represent the control mechanism.

§ 7 REALIZATIONS OF THE CONTROLLER VIA PRODUCTION SYSTEMS

The discussion of the previous section is concerned with the problem of constructively specifying the control mechanism at the level of the model or image of the outer environment. In a sense, the resulting system is the conceptual model of the way in which the controller is put together and functions. It is clearly defined in terms of the alphabets and time sets of the outer environment model and not those of the outer environment.

A control problem is not complete when a model can be controlled. The model mechanism must be mapped to a structure defined on the alphabets and time sets of the outer environment and this structure must be physically realized. Suffice it to say that the detailed structure of the implemented or realized controller always differs from the model structure and the controller must operate in an environment that is far more complex than the environment assumed for the control problem. Whereas mathematical convenience might dictate the choice of model alphabets, time sets and relations, it cannot dictate the realization.

Ideally there exists function preserving morphisms (and therefore behavior preserving morphisms) in the sense of Zeigler (1970) between the realized control system and the model. There need not however be structure preserving morphisms in the strict sense. That is, the precise way in which the controller is constructed and operates is not generally of concern in the control problem - controller realization activity. Certain kinds of state transition functions, output functions and associated trappings are required, but the precise manner in which these operations are actually performed is not of concern. Detailed structure is not necessarily preserved (and generally is not preserved). For example, a control engineer probably does not care if a digital computer or an analog computer is used to implement a process control system as long as the desired control behavior is achieved and control function carried out. The detailed structure of the two control systems so realized would however clearly be different.

The implication for modeling governments is clear. The control problem formulation can be used to provide a state decomposition of the government model which is at best functionally equivalent to the government operation. Precisely, state decomposed set theoretic model discussed in section §6 , can be mapped to the controller model IE_m. This model does not, however, describe how the government goes about producing the state transitions. It simply says that they do make such transitions.

Moreover, as was mentioned above, in order for a government to respond adaptively to the C.E., it is essential that it have some sort of image or model of the O.E. The concept "image" here is being used abstractly to refer to that portion of the I.E. which "organizes" past O.E. behaviors and thereby uses new information in generating responses. In this sense it is useful to distinguish between a long term image (LTI) and a short term image (STI). The LTI includes representations of relatively invariant properties of the O.E. Within many bureaucracies formal standard operating procedures act as an LTI. More ambient or current information is stored in the STI. The contents of the STI are used in conjunction with the LTI to determine control procedure within the I.E.

This distinction between the STI and LTI together with the explicit concerns for modeling the way in which information is processed within bureaucracies mentioned above lead very naturally to a particular way of modeling control structures - that of production systems. A production system ". . . . consists of a set of productions, each production consisting of a condition and an action (Newell, 1973b, p. 463)."

Production systems thereby explicitly incorporate theoretical statements about operation and force the modeler to be explicit about detailed control structure. Of equal importance is the fact that the mathematical structure of the allowable objects is not very constrained. Production systems therefore provide a particularly desirable method of creating detailed constructive specifications of models of government. Structure is explicitly embedded and behavior can be simulated.

Essentially the only technical constraint on the realized system that is imposed by the production system method is that the time sets be discrete. That is, T must be isomorphic to the non-negative integers. Such time sets model discrete time in the ordinary clock time notion of discrete time and event time as well. In event time, only the ordering of the occurrence of events is recorded and not the clock time of the occurrence of the event.

With any discrete time set some simplification in the abstract model of the controller is possible. Inputs and outputs in this case are sequences of symbols from the alphabets, and a next state transition can be defined. That is, given a state decomposition

$$\mathbb{E} = \Phi \circ \Gamma$$

$$\Gamma \subset Y \times Z = A^T \times E^T$$

$$\Phi \subset Z \times U = E^T \times B^T$$

with T a discrete time set. It follows from

$$tr\Gamma = \{(((y_t)^{t'}, z(t)), z(t+t') \mid (y, z) \varepsilon \Gamma \wedge t, t' \varepsilon T\}$$

that a one step transition can be obtained by setting t' = 1. That is

$$1tr\Gamma = \{(((y_t)^1, z(t)), z(t+1) \mid (y, z) \varepsilon \Gamma \wedge t \varepsilon T\}$$

Since T is discrete

$$(y_t)^1 = y(t)$$

Therefore,

$$1tr\Gamma = \{((y(t), z(t)), z(t+1) \mid (y, z) \varepsilon \Gamma \wedge t \varepsilon T\}$$

Production systems provide a very general method for constructing this one step transition function.

Notice that by using a one step transition function and by assuming the same time set for inputs and outputs, we implicitly assume that the system responds to each input. This response can be no response, the null element in B, but a response in the form of some element in B must be produced. This causes no difficulty as long as the controller has sufficient time to make the state transition and produce an output before the next input from the environment is received.

This assumption is not a limitation of the production system method and can be eliminated through use of different time sets for the inputs, outputs, and states, but this introduces additional complexity that is not needed for this discussion. It is interesting to note in passing that the time scale problem is a common one in real time computer control systems (e.g., computer control of physical processes), but is generally not a critical issue in typical general purpose information processing applications.

As mentioned above, the role of production systems in modeling governments is in constructing mechanisms to realize the one step state transition function. All information processing requirements and operations must be explicitly defined and implemented. Specifically, productions are rules stated in the form of a condition and an action: C→A. In our terms, the "condition" refers to the contents of the STI and the actions may involve policy changes (u) intended to lead to goal satisfaction or, more frequently to changes (transformations) on the STI. These changes involve modification (including deletions) of content of STI as well as addition of new content (which may appear externally as a switch in control). A more complete description of the rules governing production systems is provided by Klahr (1973):

i. The productions are considered in sequence, starting with the first.

ii. Each condition is compared with the current state of knowledge in the system, as represented by the symbols in (STI). If all of the elements in a condition can be matched with elements (in any order) in (STI), then the condition is satisfied.

iii. If a condition is not satisfied, the next production rule in the ordered list of production rules is considered.

iv. If a condition is satisfied, the actions to the right of the arrow are taken. Then the production system is reentered from the top (Step i).

v. When a condition is satisfied, all those STI elements that were matched are moved to the front of STI.

vi. Actions can change the state of goals, replace elements, apply operators, or add elements to STI.

vii. The STI is a stack in which a new element appears at the top pushing all else in the stack down one position. Since STI is limited in size, elements may be lost.

(p. 528-529).

An Example of a Production System

In order to illustrate the way production systems operate it will be useful first to discuss the basic operation of a portion of a preliminary production system model of the Saudi Ministry of Agriculture. Following this general discussion the actual production system will be treated in detail. As discussed above, a number of organizing principles have been employed as constraints on the construction of governmental control structures. Not all of those principles are directly reflected in the portion of the decision module which roughly corresponds to the Saudi Arabian Ministry of Agriculture presented here. In particular, the principles of hierarchical organization, redundancy of potential control, and multi-goal seeking are not represented because the simulation module employed here is only a portion of the total structure. In addition, since the decision module is a developmental version, the decision making properties of the module are at a relatively primitive state. In spite of these shortcomings, the module, as presented above, does serve as a useful illustration of the basic techniques and its potential.

In essence, the decision module can be conceptualized as attempting to improve domestic agricultural performance as indexed by a function with two arguments (yield = f(fertilizer constraint on yield, mechanization constraint on yield). Within the agriculture module, the yield at any given point in time is a function of the level of fertilizer application and mechanization usage. The fertilizer constraint on yield can be expressed as follows: given the current level of fertilization, what is the maximum possible yield? The mechanization constraint has a similar expression since the actual yield will be constrained by the smallest constraint. If yield is to be increased, the lesser of the two constraints must be increased. The policy variables open the government in this simple example are the amount budgeted for governmental fertilizer purchase and the amount budgeted for governmental provision of tractors.

If the Saudi government budget is increasing, the motivation for the resultant governmental output is as follows: Assume there is more money to spend, the operant constraint is (say) fertilizer and mechanization. Mechanization could be decreased since some money spent on mechanization is wasted, but since it is not known exactly how the mechanization constraint behaves with respect to budget levels, and since money is "cheap" and decreased yields are "costly," it is more prudent to take the chance of "wasting" some money by spending more on fertilizer to improve the chance of increasing yield.

From a more operational perspective, it is required that governments make observations on the environment and base outputs upon those "perceptions" of the current state of the outer environment. As a result, inputs into the decision module are symbol strings describing the current mechanization and fertilizer constraints on yield as being very high, high, moderate, low, or very low. Judgments between high and very high represent finer distinctions than does a judgment between high and moderate. This scale and the use of an ordinal description of the outer environment is based on two assumptions: The first is that the Saudi government does not have the information processing capacity to make (nor the measurement sophistication to use) finer distinctions. The second is that the Saudi's are capable of making relatively finer distinctions at the extremes of the scale. This claim about the capability of the Saudi's to process information is supported by Al-Awaji's (1971:147) description of the planning system as "institutionally fragmented and substantially ineffective," the lack of qualified manpower to staff the Saudi bureaucracy (Al-Awaji, 1971:218) for example, as of today, there still has not been a thorough census of the Saudi population.

Based upon the absolute judgments of the constraints, the decision module makes a comparison between the two constraints, resulting in relative statements such as: "The fertilization constraint is much greater than the mechanization constraint." This comparison reflects the fact that judgments are more fine grained at the extremum of the scale. One constraint is higher than another if a "boundary," i.e., the cutoff point between high and medium is crossed. For example, a very high constraint is judged greater than a high constraint, and a high constraint is judged greater than a medium constraint. If two "boundaries" are crossed, the comparison of that is very high. Thus, a very high constraint is very much greater than a medium constraint, and a medium constraint is very much higher than a very low constraint. If more than two boundaries are crossed, the comparison is 'much greater than.'

These two rankings of the constraints serve as the basic input to the choice portion of the production system. The structure of the decision module breaks the process of generating outputs into two portions. First the budget to be manipulated is determined, e.g., budget for fertilizer purchase, and/or budget for tractor purchase. Secondly, the amount of change in the budget's selected (increase a little, increase, increase a lot) is determined. The decision module uses the first relative judgment (greater than) to determine which budget to manipulate. If one constraint is less than the other, the lowest constraint is chosen. If both constraints are "about the same," both budgets are increased. If the budget to be increased has a high or very high constraint, the budget is increased "a little." If the constraint is medium, the budget (or budgets) is simply "increased." If the level of the constraint is low or very low, the budget is increased "a lot."

An input-output table which shows the decision module response to fertilizer and mechanization budget constraint inputs is given in Table 1. It is clear from this table that this particular decision module is a static system. Only the current input information is needed to define the response that will obtain. This table corresponds to the general state decomposed model of the inner environment discussed previously. Based on the previous discussion of the decision module operation, it should be clear that the production system which is used to realize the system has a more complex internal structure than is apparent from the input-output or control description of the module. That is, the production system if functionally equivalent to the system defined by Table 1 but not structurally equivalent.

In the current implementation of the decision module, increase a little means to increase the budget by 20 percent, increase means increase the budget by 50 percent, and increase a lot means to increase the budget by 150 percent. Since the actual budget changes will in the final analysis be determined by the Council of Ministers, the current procedure represents only a temporary method for allowing a portion of the decision module to operate for testing purposes. The rates of increase should not be taken too seriously. In addition, the portion of the module discussed above assumes no budget decrease takes place.

In light of the above discussion of the rules upon which a production system operates, and the non-technical (from a programming point of view) discussion of the operation of the module, the portion of the agriculture module in Figure 2 should be fairly straightforward. The system in Figure 2 is that portion of the production system that takes the judgments of the size of the constraints and determines which budgets to increase and by how much they should be increased.

There is only one operator that was implemented, the ** operator. The ** operator takes the first element in the short term image (STI) and replaces it with the double stars. Thus, if the ** expression were: OLD (**) and the first element in the STI where $$$$$, then after the execution of the **, the front of STI would be: OLD($$$$$). This operator was necessary to insure that the system would not go into an endless loop. If a production were satisfied by the elements of STI, after the operation of the ** operator, the production would not be executed again, until the masked condition were reentered into STI.

As an example, consider the operation when the STI contains the symbols YMECH MEDIUM, YFERT GREATER THAN YMECH. The system starts with production 1. Since the conditions of production 1 are not in STI, the system checks production 2. This process continues until production 12 is executed. The elements in STI match the conditions of the production, and the action portion of the production is executed. This results in 1) the elements in STI that matched the production conditions being placed in the front of STI; 2) the ** operator is applied to the first element in STI, YFERT GREATER THAN YMECH. The result is that OLD(YFERT GREATER THAN YMECH) is now the first element in STI; 3) the symbol string INCREASE BMECH A LOT is placed in the front of STI, moving all other symbol strings down one position; 4) control is passed to the first production. The system loops through the productions until none of the productions is satisfied. At that point control passes to the portion of the module responsible for taking these qualitative changes in the budgets and producing actual budget figures.

The agriculture decision module presented here serves only as a preliminary version upon which more sophisticated and reasonable modules can be based. Besides the obvious necessity of addressing the question of the validity of the simulations (see Thorson, Anderson, and Thorson, 1975 and Hermann, Phillips, and Thorson, 1975) there is need for future development in two main areas. The first is the development of the processing sophistication of the decision module. For example, it is necessary to model learning and adaptation within the bureaucracy. This development will require the use of more sophisticated inner environment models at the control system level. The second area is that of language processing. The quality of language processing becomes especially important when dealing with the international aspects of the outer environment. Diplomacy is in many respects a linguistic exercise. The capability for language processing entails that outputs from the simulations be sentences in a language. For the production systems to have this capability, several things are necessary. First the language and its associated grammar must be specified. Secondly, the routines must be written which will take sentences describing either states of the environment or actions of other actors as input and produce perceptions of the current level of goal achievement to serve as inputs into the decision making portion of the system.

§ 8 CONCLUSION

In this paper we have attempted to develop and illustrate a perspective from which complete processing models of governmental control structures can be formulated. Specifically, it was argued that governments can be viewed as information processors and that attention must be paid to specifying the internal structure of the processor. This perspective was related to that of abstract control problems and connections between goals, control mechanisms and realizations were discussed. It was shown that while control mechanisms in general do not require explicit treatment of the internal structure of the processor, a functional equivalent of control mechanisms - production systems - does require such a specification. An example of a production system model of a portion of the Saudi Arabian Ministry of Agriculture was used to illustrate these points.

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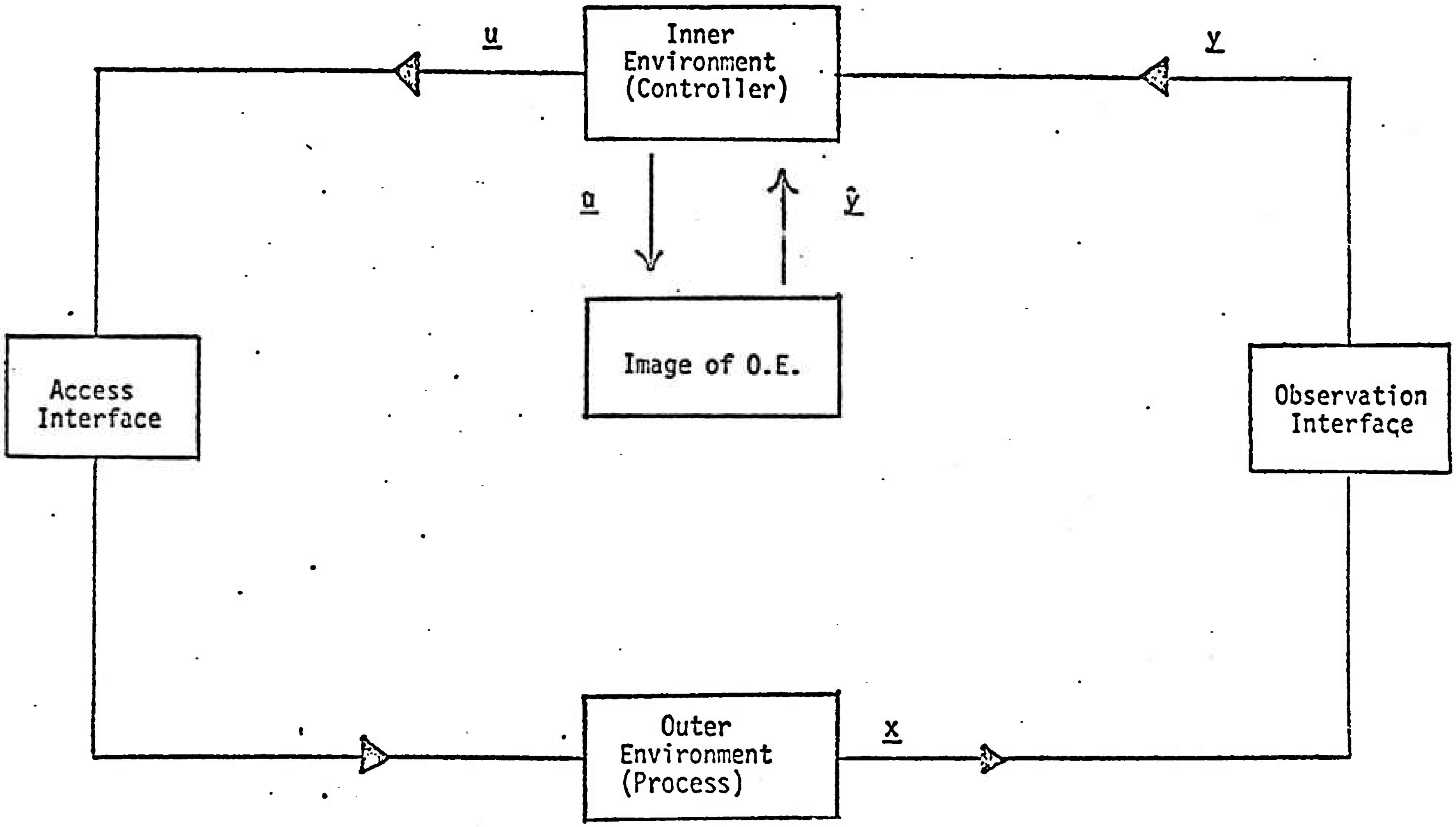

Figure 1 - Control System Structure

FIGURE 2 - A PRELIMINARY AGRICULTURE PRODUCTION SYSTEM

P1	Condition	(YMECH ABOUT EQUAL TO YFERT, YMECH LOW)
	Action	(OLD (**), INCREASE BMECH A LOT, INCREASE BFERT A LOT)
P2	Condition	(YMECH ABOUT EQUAL TO YFERT, YMECH VERY LOW)
	Action	(OLD (**), INCREASE BMECH A LOT, INCREASE BFERT A LOT)
P3	Condition	(YMECH ABOUT EQUAL TO YFERT, YMECH HIGH)
	Action	(OLD (**), INCREASE BMECH A LITTLE, INCREASE BFERT A LITTLE)
P4	Condition	(YMECH ABOUT EQUAL TO YFERT, YMECH VERY HIGH)
	Action	(OLD (**), INCREASE BMECH A LITTLE, INCREASE BFERT A LITTLE)
P5	Condition	(YMECH GREATER YFERT, YFERT VERY LOW)
	Action	(OLD (**), INCREASE BFERT A LOT)
P6	Condition	(YMECH GREATER YFERT, YFERT LOW)
	Action	(OLD (**), INCREASE BFERT A LOT)
P7	Condition	(YMECH GREATER YFERT, YMECH HIGH)
	Action	(OLD (**), INCREASE BFERT)
P8	Condition	(YFERT GREATER YMECH, YMECH LOW)
	Action	(OLD (**), INCREASE BMECH A LOT)
P9	Condition	(YFERT GREATER YMECH, YMECH VERY LOW)
	Action	(OLD (**), INCREASE BMECH A LOT)
P10	Condition	(YFERT GREATER YMECH, YFERT HIGH, YMECH MEDIUM)
	Action	(OLD (**), INCREASE BMECH)
P11	Condition	(YMECH GREATER YFERT, YMECH MEDIUM, YFERT VERY HIGH)
	Action	(OLD (**), INCREASE BMECH A LOT)
P12	Condition	(YFERT GREATER YMECH, YMECH MEDIUM)
	Action	(OLD (**), INCREASE BMECH A LOT)
P13	Condition	(YMECH ABOUT EQUAL TO YFERT, YMECH MEDIUM)
	Action	(OLD (**), INCREASE BMECH, INCREASE BFERT)

YMECH = Level of mechanization constraint
BMECH = Budget for mechanization
YFERT = Level of the fertilizer constraint
BFERT = Budget for fertilizer

Mech. Constraint \ Fertilizer Constraint	Very Low	Low	Medium	High	Very High
Very low	a lot a lot	-- a lot	-- a lot	-- a lot	-- a lot
Low	a lot --	a lot a lot	-- a lot	-- a lot	-- a lot
Medium	a lot --	a lot --	increase increase	-- increase	-- increase
High	a lot --	a lot --	increase --	a little a little	-- a little
Very High	a lot --	a lot --	increase --	a little --	a little a little

-- denotes no change.

The upper entry in each box is the fertilizer budget increase recommendation; the lower entry mechanization budget increase recommendation.

Table 1

Decision Module Input-Output Table

STRUCTURAL REQUIREMENTS

1. SPECIFICATION OF OUTER ENVIRONMENTS
    - DISTURBANCES
2. SPECIFICATION OF INTERNAL STRUCTURE OF CONTROL MECHANISM
    - DISTURBANCES
    - HIERARCHICAL ORGANIZATION
    - EVENT BASED
    - REDUNDANCY OF POTENTIAL CONTROL
3. MULTIPLICITY (AND PERHAPS INCONSISTENCY) OF CONTROL MECHANISM GOALS

WORKING DRAFT

Quasi-Experimental Effects of Military Assistance Upon International Conflict and Cooperation

Donald A. Sylvan
The Ohio State University
Department of Political Science

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QUASI-EXPERIMENTAL EFFECTS OF MILITARY ASSISTANCE
UPON INTERNATIONAL CONFLICT AND COOPERATION

Donald A. Sylvan
The Ohio State University
Department of Political Science

Effects of military assistance upon recipient nation international conflict relative to cooperation are investigated. Since traditional bivariate and multivariate statistical techniques are often conceptually inapplicable to this subject matter, a quasi-experimental design which relies upon autoregressive moving average models and exponential smoothing forecasting mechanisms is employed. Twenty-six annual observations, from 1946 through 1971, of fifteen Asian nations serve as the data base. Key findings are: (1) lump sums of military assistance tend to change the recipient nation's international conflict and cooperative behavior decidedly; (2) in a substantial majority of cases examined, the direction of that behavior change is toward increased conflict and decreased cooperation; and (3) a two year lag between military assistance and recipient nation international conflict relative to cooperation is statistically supported. Bureaucratic politics, habit, expectation, and prior deals are offered as possible reasons for these results. The paper's findings seem to refute the argument that giving military aid to a nation not involved in a war will help strengthen that nation and thereby avoid future conflict.

Is there a greater chance that a country will be involved in more international conflict relative to cooperation if that country receives one or a few large sums of military assistance[1] than if it does not? This is the primary question which I address in this paper. The answer is yes, the chance is greater.

I have divided this paper into five sections: (1) the reasons which led me to use quasi-experimental design; (2) a discussion of the various types of quasi-experimental design; (3) a description of my data set and variable operationalizations; (4) an elaboration of the path which I followed to answer my primary question, as well as a more detailed answer to that question; and (5) conclusions.

Why Use Quasi-Experimental Design?

Most statistical techniques used in international politics involve examining the patterns of two or more variables. They make the assumption that a dependent variable, domestic conflict for instance, changes in a manner related closely to the variation in one or more independent variables, such as military assistance. This seems to be a reasonable assumption in cases where the sequence resembles the following pattern: Inputs are made to a system; those inputs are eventually converted to outputs; and the outputs are sensitive to fluctuations in the inputs. For many countries, converting economic assistance to economic capacity is an example of this type of situation. Incremental changes in grants or loans can be expected to change the economic capacity of the recipient in a specifiable manner.

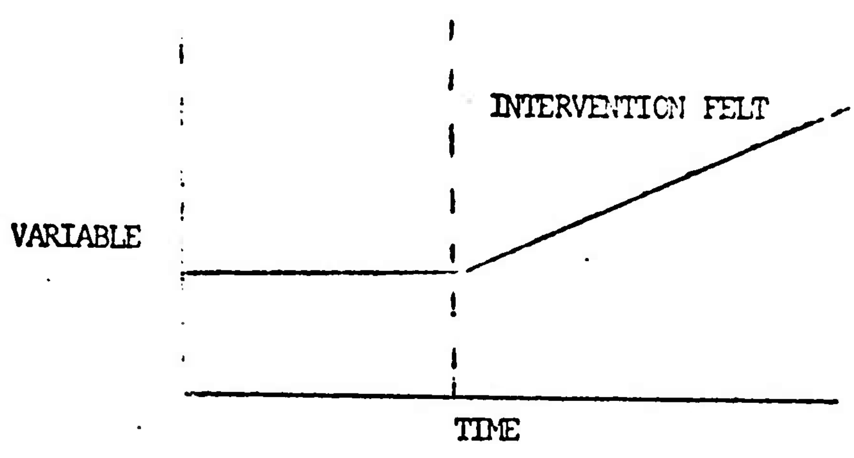
However, not all aid giving patterns are annual, and even when they are, the pattern may be one of fiscal rather than calendar years. I, therefore, hold that there is no reason to expect that variations in data on independent variables which is collected in annual segments will be reflected in similarly partitioned dependent variables. Influences on the effects of foreign assistance such as bureaucratic politics, psychological factors, and prior deals point to additional problems with traditional bivariate and multivariate techniques such as regression analysis. For instance, in a case where a large sum of assistance is given by one nation to another, and comparatively little additional assistance is given for a few years, the actions of the recipient nation (especially as captured by a variable such as international cooperation) might be motivated by a feelin of expectation of future aid from the donor. Therefore, what might appear, when observing annual segments of aid, to be a substantial decrease in value for the independent variable would not be reflected in the dependent variable's pattern of change. Receiving one lump sum of aid might cause expectation of another similar gift to motivate a recipient nation for a period of years. As I will discuss later in this paper, the same dependent variable pattern could result from either bureaucratic politics or prior deals.

These expected dependent variable patterns led me to choose quasi-experimental design over multivariate statistical techniques. I shall test the hypothesis stated by an affirmative answer to my primary question with lump sums of military assistance as the quasi-experimental intervention.

Types of Quasi-Experimental Design

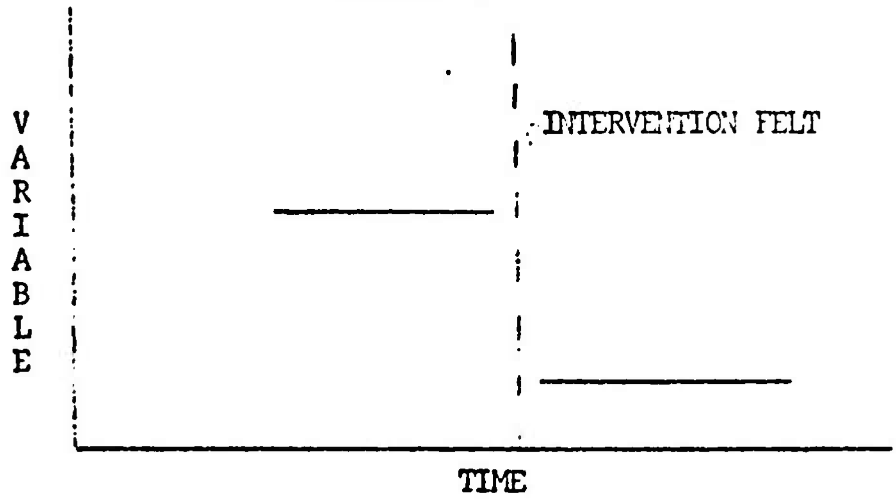
Conventional quasi-experimental techniques, as elaborated by Campbell (1969), Campbell and Stanley (1966), Caporaso and Pelowski (1971), and Caporaso and Roos (1973), can detect three types of intervention effects. By intervention effects, I mean a change in the pattern of the dependent variable over time. One pattern exists before the effect of the intervention is felt and another exists afterward. The latter two of the three effects detected by conventional quasi-experimental designs assume a stationary (i.e., constant mean for a given side of the intervention line) dependent variable pattern. The three patterns are slope change, stationary level change, and change in variability. The following is a graphic example of slope change.

DIAGRAM 1



A hypothetical case where this type of slope change might occur is one where a boost (e.g., technological innovation leading to increased production) to a nation's economy increases the rate at which the GNP grows. Stationary level change, a second type of intervention effect which can be detected by conventional quasi-experimental techniques, could look like this graphically:

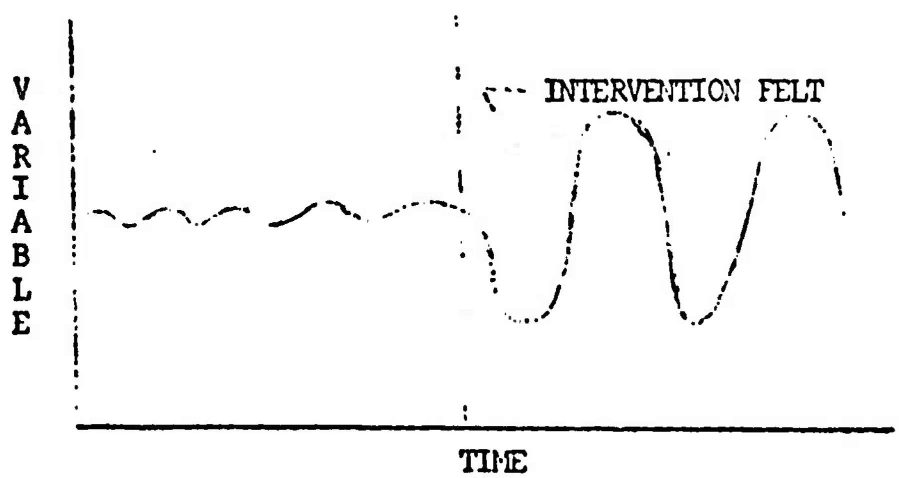
DIAGRAM 2



The 1970 floods in Bangladesh might well have produced such a change in the average individual food consumption in that country.

The third type of change is one of variability. The following diagram illustrates an example of a change in variability.

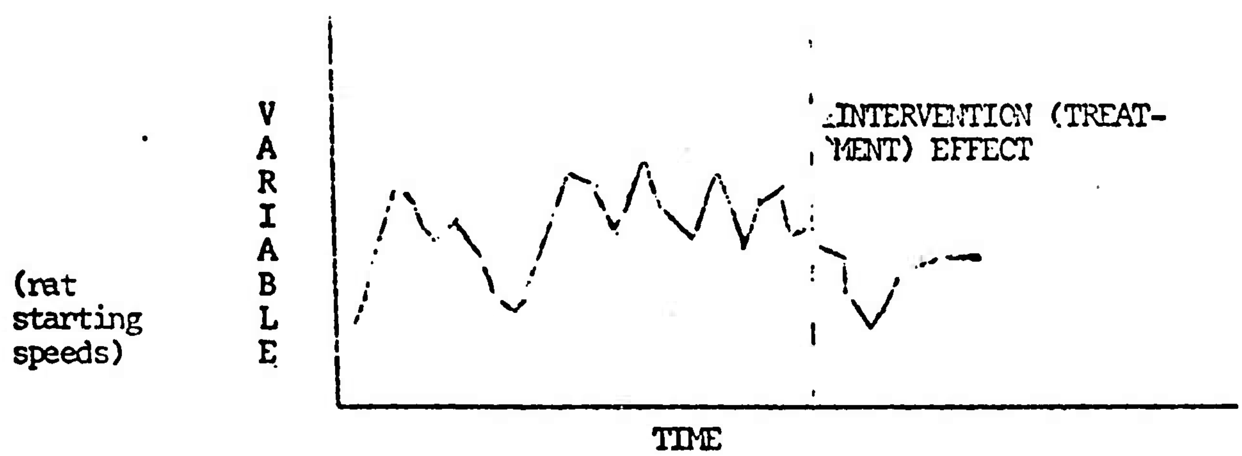
DIAGRAM 3



One example of this type of pattern change is a case where the economic stability of a nation is shaken, thereby increasing seasonal fluctuation of GNP, while the average GNP remains about the same.

The three conventional quasi-experimental tests which I have described thus far do not always reflect changes which have occurred. I shall, therefore, look at a fourth. It is a method introduced by Box and Tiao (1965) and carried further by Maguire and Glass (1967). The method evaluates the change in level between successive points in time in a non-stationary (i.e., a constant mean cannot be assumed) time series. Any situation resembling the one illustrated to Diagram 4 might well draw conclusions of either "no intervention effect" or "no determination of absence or presence of treatment effect can be made" if only

DIAGRAM 4[2]



the three tests of quasi-experimental influence which have been discussed thus far were applied. However, by applying either an autoregressive moving average (ARMA) model similar to the integrated moving average model employed by Box and Tiao, or an exponential smoothing forecasting model, changes due to intervention which are at least in part obscurred on graphs by slight drifts, cycles or trends can be detected. In addition a comparison of actual post-intervention points with forecasts of those points based on a pre-intervention model, will detect any of the three quasi-experimental effects discussed previously. I will make such a comparison, and explain it in more detail, later in this paper.

Data Set Description and Operationalizations

The data set used in this paper consists of information on fifteen Asian countries.[3] Each of the two variables, military assistance and international conflict relative to cooperation (henceforth ICC) is observed annually for the twenty-six years from 1946 through 1971.

I chose to deal with these Asian countries for three reasons. First, the region contains many military assistance recipients. Each of the countries included here have received bilateral aid for a continuous span of at least a decade since World War II. In addition, this assistance has come from all the major post-World War II aid donors: China, the U.S.S.R., the U.S.A., Japan, and Western Europe. Second, the distribution of aid has varied decidedly. The post-World War II period in Asia has witnessed wide variations both within and between nations on the amounts of aid received (See Sylvan, 1974, Table 3-2). Third, relatively reliable data was more readily available for Asia than for other regions which may have had similar characteristics with respect to the first two reasons.

One of the two variables considered in this paper is military assistance. It is operationalized here as the amount of military aid which a nation receives in a year divided by that nation's military expenditures. The demoninator is included in order to capture the aid's impact. My argument is that two million dollars of military hardware will mean less to a country with an extremely large military budget than to a nation with a small military budget. My primary sources for the military assistance variable were Bendix (1971) and the S.I.P.R.I. yearbook (1972).

International conflict relative to cooperation (ICC) has two equally weighted components. The international cooperation index consists of information on diplomatic visits bilateral and defense treaties, and shared U.N. voting. Values for each of these three variables are recorded for each country for each year. The highest such value for each variable is then given a score of 1000, while the lowest is set equal to zero. This creates an interval scale from which scores are assigned to all other observations. The three scores for each country-year are then added to arrive at a total for the international cooperation component. An international conflict component is then created in an identical manner, with the three contributing variables being territorial disputes, minority disputes and intensity of violent conflict. The total international conflict score is then subtracted from the international cooperation score to arrive at an ICC score for each country-year. Bendix (1971) served as the data source.

Description of Quasi-Experimental Design Steps, and Answer to Primary Question

I followed six steps in answering my primary question through quasi-experimental design. The six were (1) choosing a control and an experimental group; (2) specifying a lag time; (3) forecasting post-intervention effect ICC values for each year in each country; (4) the "absolute value" test; and (5) the directional test. The last two steps include interpretation of results. I shall now describe how I went about performing each of the five procedures, and report the results, thereby answering my primary question.

Choosing an experimental and a control group was the first step in my design. I argue that military assistance should only be treated as an intervention in cases where a country has received a lump sum of it. Therefore, only if a country had either (1) military assistance value which exceeded one (i.e., in a given year, military aid to a country was larger than the country's national military expenditure) or (2) an increase of over twenty times in military assistance values from one year to the next, did I include it in the experimental group. These two alternative criteria, then, become my operationalization of lump sum.[4] Based on these criteria, then, my experimental group consisted of Afghanistan, India, Indonesia, Laos, South Korea, Taiwan, and Thailand. The remaining eight nations constitute the control group. One challenge to any quasi-experimental design (see Campbell and Stanley (1963), p. 70) is that the experimental and control groups reflect something other than the division which they were designed to reflect. I have compared my two groups on a number of attributes and found none which clearly divide them into the two groupings examined here.

Dealing with the issue of time lags was the second task in my design. For this step I had to decide when I thought the lump sum of military assistance would take effect on the recipient's ICC behavior. In Sylvan (1974) I argue that a number of variables such as economic capacity, aid dispensing mechanisms and national integration intervene in converting assistance to ICC behavior. There, I conclude that a four year lag is appropriate. The body of this paper presents tests with that four year lag. The Appendix, however, tests zero, one, two, three, and four year lags, and finds slightly stronger results with a two year lag.

In cases where my lump sum criteria are met more than once for a country,[5] I treat the first lump sum observation as the intervention. The impression is made with the first gift. I argue, for example, that once a nation actually receives one lump sum of military assistance, its altered behavior pattern is set.

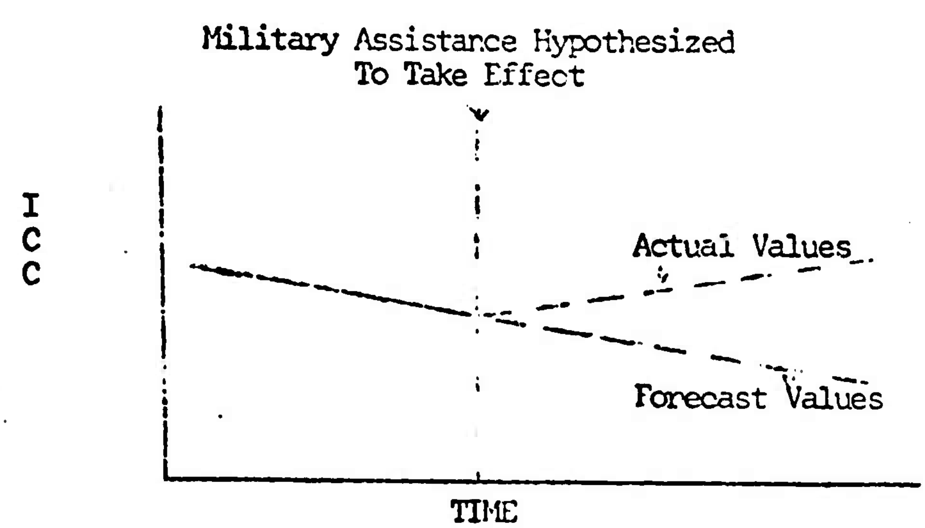
Step three was to forecast ICC values for all post-test years for each country, on the basis of a model built on the data for each country's pre-test years. I did this first with a four year lag and an autoregressive moving average (ARMA) model.[6] The ARMA model treated ICC for a given year as the dependent variable, and ICC for the previous time point, year for the previous time point, and an error term as the independent variables. In equation form, this means

$ICC_t = \alpha ICC_{t-1} + \beta\, year_{t-1} + e_t + \gamma\, e_{t-1}$, where α, β, and γ are coefficients, and e = error of ICC (which is theoretically accounted for by the ARMA random normal process). Note that for the first post-test year, ICC_{t-1} is an actual value, but it is a forecast value from then on. This is consistent with using only pre-test values to determine the effect of the intervention.

For the nations in the control group, I chose the midpoint of the available ICC time series as the intervention effect point. I did so because that point best approximated the intervention effect point for experimental group countries. The method by which I forecast ICC values for the control group countries' post-test period was identical to the procedure for the experimental group.

Step four in my quasi-experimental design was performing the "absolute value test." This is the first comparison between forecast and actual post-intervention effect ICC values. My general hypothesis is that experimental group forecasts should be less accurate than post-intervention effect forecasts for the control group. That hypothesis follows from the assumption that military assistance has an impact upon ICC behavior. Diagram 5 illustrates my point:

DIAGRAM 5



For experimental group countries the 'aid effect line' has a meaning, and one, therefore, would expect the difference between actual and forecast

ICC values to be greater than for control group countries, where the line is artificial. In the absolute value test, the percentage error[7] of the forecast value is computed in each post-test year by the following formula:

$$\text{percentage error} = \frac{|\text{actual-forecast}|}{1/2\ (\text{actual} + \text{forecast})}$$

After calculating the absolute value of the percentage error of the ARMA forecast of ICC for each year for each country, I averaged those absolute values for each country. Those figures are reported in Table 1. In order for those figures to relate to the primary question of this chapter, calculations of group means for the experimental and for the control groups are necessary. Such group means for all fifteen countries can also be found in Table 1.

TABLE 1

ABSOLUTE VALUE TEST FOR A QUASI-EXPERIMENTAL EFFECT OF MILITARY ASSISTANCE ON ICC

Experimental Group
(higher error percentages expected)

Country	Average of Absolute Value of Error Percentages of ARMA Forecasts of ICC
Afghanistan	31.804
India	43.341
Indonesia	75.261
Laos	58.422
South Korea	66.452
Taiwan	104.151
Thailand	12.250
GROUP MEAN	55.954
GROUP SUM	391.681

Control Group
(lower error percentages expected)

Burma	28.038
Cambodia	39.678
Ceylon (Sri Lanka)	53.552
Japan	17.831
Malaysia	16.518
Pakistan	17.577
Philippines	11.707
South Vietnam	59.024
GROUP MEAN	30.491

The logical next question is how significant the results reported in Table 1 are. My initial inclination was to apply a t-test of the difference of means. However, I have no reason to assume that the population of my statistical universe is normally distributed. Non-parametric statistics such as Mann-Whitney U would be another option, but I reject their requirement that I ignore information by considering my data to be ordinal rather than interval in nature. One reasonable alternative is a simple comparison of group means to see if they differ in the expected direction. Table 1 shows us that the experimental group mean (55.954) is, as predicted, higher than the control group mean (30.491). The appendix shows us that all other lags also exhibit results in this direction. As hypothesized, the experimental group post-test forecasts was always less accurate than control group post-test forecasts. Military assistance appears to be having the expected effect on ICC behavior.

To further test these preliminary findings, I have adopted an approach which is entirely different than any discussed thus far.[8] Instead of treating the fifteen Asian countries as a random sample of the world, I leave it to each reader to decide how representative this group is of the Third World aid recipients to which I would like to generalize. The variety of aid donors and aid amounts in Asia during the 1946-1971 period lead me to see them as reasonably representative. However, the test reported here makes no assumption that the countries or data studied here are statistically representative of any larger group. Instead, it treats the fifteen nation groupings as its universe. It asks the question, "Given the actual distribution of the 15 country average national error percentages from which samples of size seven are drawn, exactly how likely is it that a seven nation sum of average error percentages would be equal to or greater than the sum of average national error percentages for the seven nation experimental group?" No approximations or statistical assumptions are involved because the universe is known. The answer for the data in Table 1 to the question just posed can be found in Table 2.

TABLE 2

CUMULATIVE PROBABILITIES OF 7 COUNTRY GROUP SUMS GIVEN TABLE 1 ERROR PERCENTAGE VALUES

Seven Country Sum of Absolute Values of Average National Error Percentages	Probability of That Sum or More
211	.95
229	.90
241	.85
251	.80
259	.75
267	.70
275	.65
282	.60
289	.55
296	.50
303	.45
310	.40
317	.35
325	.30
333	.25
342	.20
352	.15
365	.10
382	.05

Table 2 tells us for instance, that seventy-five percent of the possible seven country sums of absolute values of national error percentages were either equal to or greater than 259. From Table 1 we see that the sum for the seven country experimental group was 391.681. Table 2 tells us that less than five percent of the seven country sums were 382 or higher. Actually, there is only a .030 chance of achieving the experimental group sum or higher given the distribution of error percentages in Table 1. Except for the zero year lag, Appendix Table 1 shows us that for all lags tested, the results would be obtained 7.5 percent of the time or less.

This means that those countries which received a lump sum of military assistance exhibited a substantially greater departure of ICC from the amount forecast for the post-test period than did countries which did not receive such assistance. These test results are clearly consistent with an answer of yes to this paper's primary question.

A directional or raw value test served as the fifth and final step in my quasi-experimental design. This directional test directly questions a recommendation such as, "We should give military assistance to country x. After all, they are not now involved in a war (i.e., their present national military expenditures are not very high), so giving them military assistance will help strengthen them and thereby avoid future conflict." With this step, I tested to see whether the experimental group exhibited higher levels (with respect to forecasts from a pre-test model) of international conflict with respect to cooperation (as opposed to merely exhibiting the higher deviations from forecasts which the absolute value test showed) in the post-test period than did the control group. The initial steps in this directional test were identical to the initial procedures in the absolute value test. Both forecast ICC for each post-test year and compare those forecasts with actual post-test values. However, the directional test uses the raw value of the error percentages rather than the absolute values. This is reflected in the formula

$$\text{percentage error} = \frac{\text{actual forecast - forecast value}}{\text{1/2(actual + forecast value)}}$$

TABLE 3

RAW VALUE OR DIRECTIONAL TEST FOR A QUASI-EXPERIMENTAL EFFECT OF MILITARY ASSISTANCE ON ICC

Experimental Group
(higher or more positive error percentages expected)

Country	Average of Raw Value of Error Percentages of ARMA Forecasts of ICC
Afghanistan	-25.475
India	5.692
Indonesia	- 9.424
Laos	23.417
South Korea	40.807
Taiwan	80.987
Thailand	11.035
GROUP MEAN	18.148
GROUP SUM	127.039

Control Group
(lower or more negative error percentages expected)

Burma	11.074
Cambodia	-18.553
Ceylon (Sri Lanka)	-48.663
Japan	5.469
Malaysia	-16.202
Pakistan	-17.112
Philippines	- 7.733
South Vietnam	-56.071
GROUP MEAN	-18.474

As Table 3 reveals, the experimental group mean was 18.148, while the control group mean was -18.474. This seems to be a clear cut difference in the hypothesized direction. This paper's appendix shows us that the group means are very close for the zero and one year lags, while the other lags exhibit differences in group means which are more clear cut, and in the hypothesized direction. Among the appendix findings, the two year lag again produces the most striking result.

To substantiate the directional (or raw value) test differences of means findings, I again relied upon a probability test given exact distributional data. It showed that a value equal to or greater than the experimental group sum reported in Table 3 (127.039) would only occur with a .017 probability. In other words, this result is in a select group of only 1.7 percent of the strongest results attainable with the distribution of error percentages reported in Table 3. Appendix Table A-2 shows weak results for zero and one year lags on the directional test, with stronger results for the other lags, two years exhibiting the strongest.

Results such as the .017 probability just reported clearly move in the direction of a "yes" answer for this paper's primary question.

The policy recommendation mentioned at the beginning of this step seems resoundly refuted: the situation where military aid is given to a country which is not in a war (comparatively low national military expenditures) is exactly the situation which this test shows is likely to lead to higher levels of conflict than if the assistance were not given.

In an effort to explain why I have found that there is a greater chance that a country will be involved in more international conflict relative to cooperation if that country receives one or a few large sums of military assistance than if it does not, I shall return to the three alternative explanations advanced earlier. The three are bureaucratic politics, psychological factors, and prior deals.

One bureaucratic politics explanation of the results would be attributing them to a bureaucrat in a donor nation who sought an increase in his or her national leverage. Such a bureaucrat might have reacted quickly as a conflict broke out, and juggled" the present and unreleased past figures on amounts of military assistance to make it appear as though (s)he foresaw the conflict and tried to avert is by giving military aid to the side which the bureaucrat now knows his or her government favors. Another bureaucratic politics explanation of the results is even more amoral. It is possible that a bureaucrat identified with the military sector in a donor nation sought to improve his position. He purposely manipulated military assistance to encourage war, because war demonstrates uniqueness, and in a zero sum budgeting game uniqueness is quite helpful in improving one's position. A third bureaucratic politics explanation might involve the bureaucratic politics of a recipient nation. A recipient nation bureaucrat might have helped hasten the onset of conflict in order to strengthen the military institutions of his country.

Habit and expectation are the two major psychological factors[9] which I feel might explain my results. Both factors can help interpret reactions of recipients to lump sums, as opposed to regular annual sums of military assistance. In the case of habit, the recipient continues to reap many of the benefits of the aid (e.g., a type of military hardware which does not require a great deal of maintenance), and reacts as though the aid were continuing at a constant level. If this were the case, the results could be interpreted as if they were regression results: increased amounts of military hardware on hand produces increased conflict. In the case of expectation, a nation might become involved in more conflict because it expects its military assistance to increase.

A third possible explanation of the results would be a prior deal. In a case where it would be advantageous to a donor to see a war change the status quo, that donor could make a deal with an aid recipient that if the donor supplied an abundance of money, the recipient would cooperate with the donor by going to war with a third country.

CONCLUSIONS

Is there a greater chance that a country will be involved in more international conflict relative to cooperation if that country receives one or a few large sums of military assistance than if it does not? According to the statistical evidence presented in this paper, there is clearly a greater chance. I have advanced a number of plausible explanations for this finding, but I do not have the data to choose between them. A more thorough model of the process of converting military assistance to ICC is necessary for that. My only hint at the process is that the conversion appears to take around two years.

The clearest finding of this paper comes from the "absolute value test": lump sums of military assistance tend to change recipient nation international conflict and cooperative behavior decidedly. Directional tests have shown us that in a substantial majority of the cases the direction of that behavior change is toward increased conflict and decreased cooperation.

APPENDIX: TESTING DIFFERENT TIME LAGS

As noted in the body of this paper, my original research pointed toward a four year lag between the time military assistance is given and the time such assistance is reflected in ICC behavior. The tests presented thus far dealt only with that four year lag. In this Appendix, I present tests of 0, 1, 2, 3, and 4 year lags.[10] Because I changed academic institutions between the original and follow-up tests, I can no longer readily access an autoregressive moving average (ARMA) forecasting routine which is applicable to a 26 year time series. Therefore, the tests reported in this Appendix are based on a different, slightly less accurate, forecasting model. The forecasting routine uses exponential smoothing, and was developed by James A. Bartos and David G. Fish (1974), as adopted from Winters (1960). Like ARMA forecasting, the exponential smoothing routine adjusts for trend, but not as finely. However, I hold that as long as I use the same forecasting algorithm for each country included in a given comparison of country groupings, any inaccuracy or distortion will be constant, and thereby cancel out. In other words, I can compare experimental and control groups if both sets of error percentages are generated by the same forecasting routine. Comparisons of ARMA and exponential smoothing forecasts without adjustment for a constant factor would be invalid, however.

Table A-1 presents "absolute value" error percentages for 0, 1, 2, 3, and 4 year lags as obtained with the exponential smoothing forecasting routine.

TABLE A-1

"ABSOLUTE VALUE" ERROR PERCENTAGES

Experimental Group
(higher error percentages expected)

Country	0 Year Lag	1 Year Lag	2 Year Lag	3 Year Lag	4 Year La
Afghanistan	85	32	42	14	51
India	75	727	6568	591	276
Indonesia	114	1166	66	14	12
Laos	40	173	48	160	78
South Korea	46	49	208	85	61
Taiwan	252	144	94	113	109
Thailand	70	11	23	8	11
GROUP MEAN	97.4	328.9	1007	140.7	85.4
GROUP SUM	682	2302	7049	985	598

Control Group
(lower error percentages expected)

Burma	324	216	75	15	32
Cambodia	38	43	43	44	46
Ceylon	36	31	36	27	52
Japan	88	25	24	45	26
Malaysia	62	43	40	20	39
Pakistan	9	18	11	17	16
Philippines	14	7	12	12	13
South Vietnam	59	149	67	48	36
GROUP MEAN	78.7	66.5	38.5	28.5	32.5
PROBABILITY OF EXPERIMENTAL GROUP SUM OR GREATER	.312	.075	.026	.029	.041

Note: All country entries are average national error percentages of post-intervention effect forecasts.

This table is constructed in a manner parallel to Table 1, and its results are discussed in the body of this paper. I shall merely re-emphasize here that "probability of experimental group sum or greater" refers to the same exact probability testing procedure elaborated upon in the text and illustrated for another example with Table 2. The reader will note that while four of the five probabilities are extremely strong, a two year lag produces the strongest.

Table A-2 presents results for the directional test. As discussed in the text, it parallels Table 3, and again finds two year lag results to be the strongest.

TABLE A-2

"RAW VALUE" OR "DIRECTIONAL" ERROR PERCENTAGES

Experimental Group
(higher error percentages expected)

Country	0 Year Lag	1 Year Lag	2 Year Lag	3 Year Lag	4 Year Lag
Afghanistan	85	31	42	8	51
India	43	727	6568	591	276
Indonesia	54	-632	66	14	11
Laos	-31	132	-28	-5	-14
South Korea	-26	13	178	83	9
Taiwan	252	-144	-[illegible]3	-113	-109
Thailand	-70	-10	23	-2	7
GROUP MEAN	43.9	16.7	958	82.3	33
GROUP SUM	307	117	6706	576	231

Control Group
(lower error percentages expected)

Country	0 Year Lag	1 Year Lag	2 Year Lag	3 Year Lag	4 Year Lag
Burma	324	216	75	4	22
Cambodia	26	29	27	23	2
Ceylon	-35	-26	16	-17	18
Japan	88	-19	13	39	16
Malaysia	-62	-43	-40	-[illegible]	21
Pakistan	-4	-17	6	14	-14
Philippines	9	3	-4	5	-3
South Vietnam	43	54	67	43	27
GROUP MEAN	485	24.6	20	12.8	13.4
PROBABILITY OF EXPERIMENTAL GROUP SUM OR GREATER	.473	.528	.215	.332	.367

Note: All country entries are average national error percentages of post-intervention effect forecasts.

NOTES

[1]As elaborated upon later in this paper, military assistance is operationalized by dividing aid by national military expenditures.

[2]Taken from Maguire and Glass (1967), p. 747.

[3]Afghanistan, Burma, Cambodia, Ceylon (now Sri Lanka), India, Indonesia, Japan, Laos, Malaysia, Pakistan, Philippines, South Korea, South Vietnam, Taiwan, and Thailand.

[4]There is a clear enough division between groups, though, so that almost any similar criteria would have resulted in the same experimental and control groups.

[5]No country meets them more than three times.

[6]For a more detailed description of autoregressive moving average models, see Box and Jenkins (1970), Werbos (1974), and Sylvan (1974).

[7]The error percentages reported in Tables 1 and 3 may be deflated because of the assumption that the error term and the independent variable are uncorrelated. While this bias cancels out in the probability test reported next, the reader should not interpret the percentage error terms literally. For an excellent discussion of bias present in assuming 0 correlation between error term and independent variable, especially in cases (such as this one) where the dependent variable at t-1 is treated as an independent variable, see Hibbs (1974).

[8]I thank Stuart Thorson for his suggestion to use this test.

[9]For a discussion of the related subject matter of cultural and other factors underlying American attitudes toward foreign aid, see Geiger and Hansen (1968).

[10]For an example of experimentation with different lags on a different subject matter, see Terhune (1970). I did not test lags beyond five years, because of the decrease in the number of points in the post-test period in a total 26 year time period.

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Goals and Goal-directed Behavior In International Relations*

Howard Tamashiro

Department of Political Science
The Ohio State University

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The study of international relations, as are all the social sciences, is deeply concerned with purposive behavior, and goal-directed, or teleological systems. Indeed, nothing in the field of international relations is more basic than the notion of goal-directed behavior for "political" activities are largely "purposive" activities. Whether under the rubric of interests, objectives, ends, or goals, scholars have, either implicitly or explicitly, always thought of and explained international politics and foreign policy in terms of preferred end-states. Yet, despite the fundamental conceptual role played by goals in the understanding of international politics, its treatment as a concept has been unsatisfactory. For a variety of reasons to be discussed later, it remains an elusive, primitive term defying adequate conceptualization.

THE FUNCTION OF GOALS IN INTERNATIONAL RELATIONS THEORIZING

Any science aspiring to theory must assume some sort of underlying regularity in the world. Without positing such regularity, descriptive laws of nature and scientific predictions become impossible. Researchers would be forever limited to particular statements on unique events. Generalizations, without some posited order in one's universe of discourse, would be, at best, blind leaps of faith.

In the physical sciences, the regularity assumption is provided by a "mechanical postulate" which presupposes an order in the physical world independent of spiritual or metaphysical forces. Physical entities are assumed to exhibit regularities in behavior about which scientific theories can be framed.

In the social sciences, the regularity assumption is often introduced by the notion of goal-directed behavior. As noted by Riker and Ordeshook:

> When one is generalizing about the physical world, the conventional postulate is the mechanistic one; that is, we rule out vitalism, divine intervention, luck, witchcraft, and so on. When one is generalizing about the social world, however, where, clearly, the actors are vital, one can hardly rule out vitalism. Hence the postulate for regularity changes to a notion of the pursuit of goals; that is, we assume actors in society seek to attain their purposes.[1]

Attributing goal-directed behavior to social entities allows us to make sense of observed regularities in social behavior. It provides a rationale for theorizing and predicting regularities with some degree of assurance. It provides a specification for the meaning of an action and how it might be distinguished from other forms of behavior.[2] Finally, attributing goal-directed behavior to a social entity often eases the knowledge requirements of the entity's internal structure necessary for prediction. For example, in an economic context, Herbert Simon notes:

> If we know of a business organization only that it is a profit-maximizing system, we can often predict how its behavior will change if we change its environment -- how it will alter its prices if a sales tax is levied on its products. We can make this prediction -- and economists do make it repeatedly -- without any detailed assumptions about the adaptive mechanism, the decision-making apparatus that constitutes the inner environment of the business firm.[3]

Two basic strategies exist for employing the goal-directedness assumption in social science theorizing. Riker and Ordeshook call them revealed preference and posited preference.[4] In the revealed preference procedure, rules of behavior (e.g., transitivity, utility maximization) are posited and then applied to observed behavior to discover those goals consistent with the aforementioned posited rules and observed behaviors. Hence, under the revealed preference strategy, goals are inferred from (1) assumptions about behavior, and (2) behavior actually observed.

In international relations research, revealed preference strategy is illustrated by what Graham Allison calls the "rational actor" mode of analysis:

> If a nation performed a particular action, that nation must have had ends toward which the action constituted a maximizing means. The Rational Actor Model's explanatory power stems from this inference pattern. The puzzle is solved by finding the purposive pattern within which the occurrence can be located as a value-maximizing means.[5]

In a somewhat stylized example, if an analyst assumes Communist nations with strong armies seek to increase their spheres of influence, and then notices the People's Republic of China (PRC) maintains a very large army, he could conclude, under the rational actor approach, the PRC's goal is to apply external, strategic military pressure abroad. Unfortunately, this mode of analysis is far from foolproof since an imaginative analyst, given a set of observed behaviors and posited rules of behavior, can usually find some set of goals consistent with his observations and opening assumptions.

The second, posited preference strategy assumes a given goal for an actor and certain rules of behavior. The actor's behavior is then inferred. If these inferences are confirmed by observation, our confidence both in the initial posited goals for the actor and the posited rules of behavior is increased. But, if our inferred behavior for the actor doesn't occur, then either our posited goals or posited rules of behavior, or both are faulty.

In general, the analytical choice between revealed preference and posited preference is dependent on the problem being addressed. Often, research requires shifting between the two methods. For example, we noted earlier how an analyst, operating from a revealed preference perspective, might conclude the People's Republic of China's goal (we are, of course, assuming here a unitary actor perspective) is the aggressive exertion of military pressure abroad. However, assume further observations reveal the PRC's foreign activities to be defensive and cautious, contrary to posited preference expectations. The analyst would then be forced to alter his posited PRC goal (i.e., aggressive military expansion) or his initial, posited rule of behavior (i.e., Communist nations with strong armies are expansionist) or both, and then restart his analysis. In the process of such modification -- formulating goals and rules of behavior, comparing inferred behavior with observed behavior, reformulating goals and rules, etc. -- the analyst shifts from posited preference to revealed preference and back again. Both modes are necessary, one complementing the other.

To be of analytical value, the cyclic use of posited and revealed preference strategies requires careful conceptualization and explicit framing of theoretical assumptions. Such conceptual standards, unfortunately, have not often characterized the past treatment of goals and goal-directed behavior in the study of international relations. We now examine the conceptual state of goals in international relations research.

PAST TREATMENT OF GOALS IN INTERNATIONAL RELATIONS

Among traditional international relations scholars, goals have often been stipulated in an a priori manner. Hans Morgenthau, for example, saw power as the constant aim dominating international politics. Unfortunately, Morgenthau's historical style of analysis and his strong prescriptive bent clouded his theoretical intent. While initially defining power as psychological control between individuals, Morgenthau applied the term to nations without addressing the resulting levels of analysis problem. Further, depending on the context and Morgenthau's purpose, power could be a relationship, a goal of policy, a stimulus for policy, and a means for realizing policy ends. Given this unusual flexibility in the use of the term, almost every conceivable behavior was interpreted as a pursuit for power.

Operating from a similar, traditional perspective, Haas and Whiting[6] identified self-preservation, self-extension, and self-abnegation (i.e., policies of retrenchment or withdrawal) as basic goals in international politics. To take a final example of traditional goal positing, Puchala's[7] list of fundamental goals included self-preservation, security, prosperity, prestige, and peace. Generally, these enumerative, a priori approaches to the goals of international politics were unsatisfying for similar reasons. First, they were defined too abstractly and imprecisely to be of much analytical use. What does it mean, for example, for a nation to strive for self-preservation or prosperity? How can one decide whether particular policies are in accord with such nebulous goals as peace or security? For example, was American intervention in Vietnam a contribution toward U.S. security or self-preservation? Second, a priori stipulation of national goals implied a homogeneous, unitary actor interpretation of nations which wasn't capable of treating internal policy dissension or bureaucratic political processes. Differences over concrete questions of policy implementation were left unexamined. Further, goal priorities and goal conflicts were difficult to handle at this rarefied level of abstraction. Third, the dynamic quality of goal formulation and transformation was ignored. Stipulation of a priori goals implied a permanence of interest independent of internal politics, external international change, and time which was highly questionable. For example, even such a primary "goal" as national self-preservation might, in extraordinary circumstances, be suspended as in 1938, when Austrians voted overwhelmingly for Anschluss and political domination by Nazi Germany.

Another approach toward goals adopted by traditional scholars involved the identifying of underlying goal dimensions and the constructing of a classification based on these dimensions. For example, time has served as an underlying dimension for goal classification (Organski's long-range vs. immediate goals). Other goal dimensions proposed: core values vs. instrumental ones (Holsti, 1967), vital vs. secondary goals (Hartmann, 1957), general vs. specific goals (Organski, 1968), competitive vs. absolute (Organski), unified vs. divergent (Organski), national vs. humanitarian (Organski). Unfortunately, these approaches also suffered from the same conceptual problems noted above. While perhaps descriptively appealing, these goal images were too abstract, too nebulous, to capture the dynamic, diverse, and contingent quality of goals and goal-directed behavior.

The weaknesses connected with this sort of traditional, macro-level conceptual treatment became increasingly evident as scholars adopted more formal research strategies. Operationalization and the demands of mathematical tractibility often required more theoretical structure for goals than was available. This problem of structure, what Mesarovic and Thorson refer to as constructive specification,[8] was met in a number of ways. One strategy sidestepped the goal problem by adopting a macro-level perspective depending on aggregate indicators for description and international trend analysis. Work in international integration (Deutsch et al., 1957), international organizations,[9] and field theory (Rummel, 1963) serve as examples. Such monitoring and mapping activities allowed the use of statistical or linear algebraic analyses while avoiding the explicit treatment of goals.

Another strategy dealt with goals by positing them at a particular level of analysis. Game theoretic treatments, for example, viewed goals in terms of relative payoffs between players in highly structured conceptual settings. The players were seen as unitary actors at a fixed level of analysis (such as the nation-state, the bureaucracy, or the individual). By abstracting away the complexity of goals and goal contexts, the analytical power of game theory could be utilized to the fullest measure. Similar conceptual simplifications concerning goals, for the sake of mathematical tractibility, were made in arms race process modelling à la Lewis Richardson (Richardson, 1960). Here, the differential equations which specified national arms race behavior were the posited goals.

Similar goal positing was also adopted when international systems theorizing, characterized by equilibrium interpretations of system behavior, came into vogue. McGowan,[10] for example, collapsed the myriad goals pursued by groups within a nation-state using a series of difference equations. National goals were interpreted as the need to "dampen" the paths produced by these difference equations over time -- a rather unorthodox goal conception, required by the mathematical techniques McGowan wished to employ.

Unfortunately, the international systems approach, like its predecessors, failed in general to deal meaningfully with purposive behavior. The approach often lapsed into an anthropomorphic mode of explanation whereby international systems assumed the character of holistic entities imbued with imminent, purposive rules of behavior. For example, Morton Kaplan, in his systems approach to international politics (Kaplan, 1957) posited "essential rules" for system members deemed necessary for a system's existence. Yet, the nature of these rules was unclear. They might be interpreted as operating "automatically," akin to Adam Smith's invisible hand; they might be "semi-automatic," requiring the conscious rule promoting efforts of "select" nations; or they might be "manual," requiring the full and conscious participation of all nations in the system.[11] In short, these rules of behavior seemed somehow prior to concrete activity. This same "a priori" treatment of purpose as a need-fulfilling function of a reified system of components also characterized McGowan's theoretical treatment of national foreign policy mentioned earlier.

The general systems approach of Talcott Parsons[12] was another example of a macro-level systems perspective with an "a priori," need-fulfilling quality. Operating at a high level of abstraction, Parsons defined four essential functions every social system must satisfy to assure its survival -- pattern maintenance (i.e., the preservation of essential system traits), adaptation, goal attainment, and integration (i.e., the coordination of system components). Like Kaplan's work, the Parsonian systems perspective suggested innate system purposes lurking behind the scene.

Unfortunately, treating need-fulfilling functions of a system (what sociologists call the functional requisites for survival) as system goals was misleading. While a strong empirical connection between need-fulfilling, survival functions and system goals wouldn't be surprising (since those systems available for observation are those most likely to have survived for some time), survival functions and goals needn't be identical. For example, explaining the increase of white cells in the bloodstream during infection in terms of its survival function and natural selection would be biologically sound; explaining it as a collective goal pursued by the body would be bizarre. Similarly, in a political context, American actions in Vietnam might be explained in terms of Presidential goals; but, less plausibly so in terms of national functional requisites, again suggesting survival functions and goals needn't be synonymous. In general, if need-fulfilling functions resemble goals, the resemblance is empirical, not definitional. Nothing requires that goals have survival value.

Yet, despite the shortcomings of the systems school, it did reemphasize, though not always explicitly or consistently, an important aspect of purposive behavior which had been obscurred by the earlier "point-blank" positing of goals. That is, the systems perspective was usually not of the form "the goal of the nation-state is power, prestige, wealth, and the like." Universal drives were not ascribed to nations. Rather, system treatments of goals made allusions, however obliquely, to the existence of a process or environment. Purposive behavior was imbedded within a context of system entities or interactions. This view, that goals are linked to some environmental context, that is, are context dependent, is important and will receive more treatment later.

When we move down to the organizational or bureaucratic level of analysis we find treatments of goals which seek to move away from goal positing and the attendant danger of reifying organizations while, at the same time, avoiding the mistake of assuming organizational goals are simply the accumulated goals of all its individual members. One approach is Stuart Thorson's use of production systems, essentially a simulation utilizing a list of "productions" (i.e., instructions) processed sequentially, to represent the control structure of a government.[13] The productions or instructions which produce government behavior are the government's goals; that is, the production system structure is the government's goal structure.[14] The production system approach is especially attractive for two important reasons. First, unlike many mathematical modeling approaches, it doesn't require a high degree of constructive specification (i.e., the formal, mathematical properties introduced in one's axiomatic structure for deductive convenience). The productions can be couched in very general, qualitative terms -- an important working and conceptual advantage since international relations has no guiding theories of any high precision. Second, since few restrictions govern the list of productions, the production system scheme has a large degree of flexibility which might be used to model multiple goals, goal conflicts, and redundancy of potential control (whereby subgoals can shift depending on internal and external circumstances). Hence, this flexibility potentially allows one to move well beyond macro-level goal positing.

Another imaginative approach, suggested by Herbert Simon,[15] involves conceptualizing organizational goals in terms of constraints or requirements which must be satisfied before an organization embarks on a course of action. In particular, organizational goals, he suggests, might be characterized by the constraint sets and goal searching criteria of the upper level decision-makers in the organization. While analyzing such constraint sets would not, by themselves, fully define organizational behavior, Simon argues they capture most of the "goal-like" properties associated with decision-making. Unfortunately, Simon's approach towards goals is not completely satisfying because: (1) the notion of constraints isn't sharply specified; (2) the upper level decision-makers, whose constraint sets are used to define goals, aren't identified clearly; and (3) all Simon's organizational examples are drawn from highly structured settings such as factory assembly lines, feed manufacturing, and investing. Nonetheless, Simon's view of goal as constraint set is intriguing because it relates goals to decision-making structure, it can treat multiple goals, and it moves beyond simple goal positing.

James Thompson suggests a different way of avoiding the reification problems connected with group goals. He defines organizational goals as goals specified for the organization by a dominant coalition. Thus, the pitfall of ascribing "intent" to an abstract organization is avoided. From Thompson's perspective, "organizational goals are established by individuals -- but interdependent individuals who collectively have sufficient control of organizational resources to commit them in certain directions and to withhold them from others."[16] Unfortunately, Thompson's conception of goals is not without difficulties. The twin problems of defining coalition goals and identifying dominant coalitions are left untreated. Like Simon's constraint approach towards goals, the dominant coalition approach remains an embryonic, suggestive attempt. However, Thompson does move beyond simple goal positing towards some notion of organizational goals which is linked to organizational decision-making structure.

Another approach towards goals, related to Thompson's dominant coalition attack, springs from an emerging movement to harness events data for foreign policy decision-making research. One events data perspective[17] defines nation goals as all goals expressed by "authoritative decision-makers" (i.e., governmental representatives with formal responsibility for policy-making) and reported publicly. Goals are never inferred from behavior.

Potentially at least, this particular events data perspective can handle multiple goals, contradictory goals, and differing goal priorities. Further, unlike Thompson's approach, the problem of identifying coalitions doesn't arise. However, the question of specifying "authoritative decision-makers" remains. Moreover, the professed goal definition is not linked explicitly to organizational processes or structure. Unlike the Thorson, Simon, or Thompson perspectives, its role is more data indicator than theoretical construct. The conceptual price paid for such operationalizing convenience may turn out to be steep indeed.

Having now reviewed some approaches to organizational goals what conclusions can we draw? First, goal positing predominates, especially among traditional international relations researchers, as a preferred mode of analysis because of its simplicity. Further, goal positing reflects a belief among many scholars that organizations, and especially nations, often have a set of "core" goals which are relatively impervious to change. The national core values idea posited by Holsti, the vital goals of Hartmann, and the general, absolute goals of Organski are all reflections of this belief.

Second, the notion of time has often either explicitly or implicitly played a significant role in goal conceptualization. Indeed, the view of goals as preferred, <u>future</u> end states implies some conception of time. Organski's long-range vs. immediate goal dichotomy, McGowan's use of difference equations implying a discrete time interval perspective, and the Richardson process equations, which assume a continuous time perspective, are all examples of time's import in goal conceptualization.

Third, the search for suitable organizational goal conceptions has dovetailed with work on organizational structure (what Thorson has referred to as control structure[18]). Indeed, it is probably no accident that, while goals are used on many levels of analysis -- the international system, nation-state, and organizational-bureaucratic levels, goal conceptualization becomes increasingly more sophisticated as one moves down the ladder of abstraction, where goals are linked conceptually to organizational processing (as in the Thorson production systems approach) or organizational structure (as in the Simon "constraints set" or the Thompson dominant coalition approaches).

A fourth related point concerns the notion of subgoals. Since organizations aren't generally directed towards a single, overarching goal, conceptual approaches which can handle multiple goals, conflicting goals, and switches in goal priorities (i.e., redundancy of potential control) are especially valuable. Such conceptual concerns require close attention to organizational structure and processing -- attention which only Thorson's production system, Simon's "constraint set," and Thompson's dominant coalition perspective seem capable of. All the other approaches appear too abstract.

A final observation concerns the notion of a setting or environment within which goals are defined. Especially with the advent of the systems perspective, researchers have focused attention on external environments and their relationships to internal organizational structure. This sensitivity to environments is important because goals depend upon the interplay between organizations and environments, upon both organizational and environmental changes. From this standpoint, the blanket positing of universal goals, characteristic of early international relations work, is decidedly inadequate.

This brief literature review on goals has revealed important definitional trends involving time, organizational structure, subgoals, and environmental setting.

The following sections of this paper will examine these conceptual themes and their implications, arguing in the end, that any useful conceptualization or organizational goals cannot afford to neglect them; that, in short, goals are context dependent.

CRITERIA FOR GOAL-DIRECTED BEHAVIOR

Before moving further we should try to capture the intuitive features of goal-directed behavior by identifying and characterizing at least some of its criteria. Such criteria will provide a necessary background for the discussion in the following section on goal-directed systems.

Gerd Sommerhoff[19] has argued the essence of goal-directed behavior is flexibility; that is, any goal-directed entity must be capable of modifying its behavior in accordance with pertinent environmental charges. The problem here is capturing this flexibility in abstract terms.

Two conditions appear necessary if an entity's behavior is to be called goal-directed. First, the causal link between action and environment with respect to a goal must be brought about by the entity. In other words, the realization of a goal must depend, in some sense, on the entity's behavior. This condition excludes cases where the fulfillment of an effect is inevitable, independent of any considerations of an entity's goal or behavior. For example, under this condition and the perspective of modern physics, a shaman who recites an incantation each night to insure next morning's sunrise would not be exhibiting goal-directed behavior.

The second condition of goal-directed behavior concerns the coupling of an entity with its environment. The coupling must be such that changes in relevant features of the environment will induce entity behavior changes. In particular, goal-directed behavior demands the existence of feedback loops which register information about the environment, and, hence, the margin of error at which an entity stands at a given moment with respect to a given goal. Further, goal-directed behavior requires some sort of internal processing capability (processing structure) which uses feedback signals to direct entity behavior. This internal processing structure incorporates within itself, by virtue of its design (e.g., the environmental variables monitored, the manipulable variables toward which behavior is directed), some abstracted image of the causal links in the entity's operating environment. For example, the behavior of a magnetic compass would qualify here as goal-directed behavior. The compass' magnetized needle provides both the feedback loop to the environment and the processing structure necessary for goal-directedness. For the compass, the environment is composed solely of magnetic lines of force. Environmental changes which do not disturb these force lines are irrelevant and have no influence on the compass' behavior. In general, if environmental changes do not alter the causal links upon which an entity's processing structure is based (i.e., the abstracted environmental image implied by the processing structure's mode of organizing and directing behavior), the entity will continue to goal-seek successfully. But, if environmental changes render an entity's environmental image inadequate, the entity will cease to exhibit goal-directed behavior. A compass placed within a strongly oscillating magnetic field, or a light-seeking mechanism placed in the dark will not goal-seek. Hence, an entity's ability to exhibit goal-directed behavior is not an innate trait, but depends on a given environment. A goal-directed entity in one environment needn't be goal-directed in another.

Further, goal-directed behavior, as specified above, cannot be unambiguously determined from observing entity behavior alone. Goal-directedness is dependent upon a particular description -- a description of an entity's internal processing structure, with all the causal assumptions imbedded in its image of the environment, and a description of the entity's environment relevant to the goal sought.[20] This description- or theory-dependent nature of goal-directed behavior can be elucidated by re-examining an example presented earlier. We noted a shaman, using incantations to insure each mornings' sunrise, would not be exhibiting goal-directed behavior because some causal link must exist between his actions and his goal (i.e., causing the sun to rise). However, the existence or non-existence of such a causal link cannot be unequivocally proven -- it arises from current theoretical knowledge in astronomy. If later developments reveal a link between incantations and sunrises or if we adopt the shaman's image of the universe as a standard for evaluation, we would be forced to call the shaman's behavior goal-directed.

Further, if the analytical perspective used to assess the shaman's behavior were switched from astronomy to say, sociology, we might argue the incantations are directed towards preserving social cohesion in the face of nature's uncertainty. By spinning a socio-psychological narrative connecting the shaman's incantations with tribal psychology, we might reasonably conclude the shaman's behavior is indeed goal-directed with respect to social cohesion. The important point here is goal-directed behavior must be treated within some theoretical context if it is to be of any analytical use. The notion of goal-directed behavior, when devoid of theory, reduces to a metaphysical assumption. Hence, if a theorist wishes to speak of goal-directed behavior, he should specify those objects which give theoretical substance to the concept -- namely, a description of the goal-seeking entity's processing structure and the entity's operating environment. Unfortunately, as revealed in our earlier literature review, this theoretical completeness is often neglected, especially in the more traditionally based international relations research. As Thorson noted, in a related context:

> All too often, especially in theories expressed in natural languages such as English, the tendency is to assume that "everyone knows" what is being theorized about. Since "everyone knows," there is no need to specify explicitly what objects make up that world. Yet, it can be argued that theories are not about the world

but about "representations" of the world (or indeed, there may be many worlds), and it is useful to make public that representation by specifying it as unambiguously as possible.[21]

In fact, the most interesting disagreements in international relations spring from different theoretical reconstructions of posited, goal-directed behavior, suggesting the crucial importance in specifying clearly one's world representation or description.

Two final points about our criteria for goal-directed behavior: first, such behavior neither presupposes the eventual realization of the goal by the agent nor the contingent possibility of the goal's attainment. Hence, searches for nonexistent objects, such as an alchemist's search for the philosopher's stone, may very well qualify as goal-directed behavior, given a suitable theoretical framework or system of beliefs for evaluating the action under study. For example, suppose an astronomer searches for a nonexistent planet, which he believes exists. If the astronomer's theoretical framework is adopted as a standard of evaluation, then the astronomer is indeed exhibiting goal-directed behavior. If, however, some other, more advanced theory, which demonstrates the impossibility of the planet's existence, is used as a standard, then the astronomer's behavior must be adjudged nongoal-directed.

The second point about our criteria for goal-directed behavior is goal realization doesn't automatically imply goal-directed behavior. According to our two goal-directed criteria and current astronomical knowledge, our shaman would not be exhibiting goal-directed behavior however much we might envy his success record.

Having established general, abstract criteria for goal-directed behavior we can further sharpen this concept by considering three basic kinds of information upon which goal-directed behavior might depend.

Karl Deutsch has observed:

> A society or community that is to steer itself must continue to receive a full flow of 3 kinds of information: first, information about the world outside; second, information from the past, with a wide range of recall and recombination; and third, information about itself and its own parts.[22]

The first type of information cited by Deutsch, information about the environment, represents one of the necessary conditions introduced earlier characterizing goal-directed behavior. However, entities which are limited to this single source of information are often extremely inflexible. They depend solely on those environmental variables "designed" or "programmed" into their processing structure. Further, the inability to update this "environmental image" renders flexible, long-term operating perspectives impossible; hence, imparting a reflex action quality to entity behavior. The story of the spy, who wished to locate the seat of American power by trailing Pentagon telephone cables and, instead, discovered the Pentagon telephone exchange, is a humorous example of goal-directed behavior dependent solely on external environmental cues. A column of army ants, programmed by nature to respond to such a constrained set of environmental cues (i.e., the presence of other army ants) that it may lock itself in a circular "suicide mill" and continue circling to exhaustion, is another graphic example of the narrowness of goal-directed behavior dependent solely on immediate environmental information. Still another, more sophisticated example is the military's experimental missile guidance system called Terrain Contour Matching. Under this system a missile's processing structure is given a digital map of its flight path in terms of topographical features expressed in altitude values. While the missile is in flight, it scans the ground below, compares its findings with its programmed course, and makes the necessary course adjustments. No updating in flight of the missile's digital map is possible, or really necessary because its operating environment, the terrain along its flight path, is, for all practical purposes, time-invariant. If, however, the terrain along the missile's path were to change significantly from its digital map values, the missile would be hopelessly lost. In general, because of the low level of sophistication displayed by such goal-seeking entities relying solely on environmental information, their heuristic value for studying international political phenomena is understandably modest.

Entity behavior guided by both environmental information and messages about changes in the entity's own internal processing structure represents the next level of potential capacity in goal-directed behavior. Devices which can monitor both their environments and internal structure have the potential of greater steering precision. Information on internal states might be used to control or even redirect an entity's sensory devices, permitting greater flexibility and precision in the identification of environmental information gathered and processed in preference to others. Further, information on internal states can be used to protect an entity's processing structure, rendering it less vulnerable to threatening environmental variations or internal malfunctions. Entities with an automatic shutoff capability such as NASA's manned launch vehicles, which are programmed to shut off if any internal malfunction is detected prior to liftoff, are examples (in late 1965, during the Gemini-6 Mission, this automatic system was activated, aborting the launch).

However, entities with environmental and internal monitoring capabilities, like their less sophisticated, servomechanistic counterparts, suffer from a very narrow time perspective -- they have no capability for storing and retrieving past experience. The limitations imposed on goal-directed behavior unaided by a recall capability are suggested by Frances Fitzgerald's description of the "timeless quality" characterizing Vietnamese pacification efforts -- the "Really New Life Hamlet" program (1967) superceding the "New Life Hamlet" program, which, earlier, had superceded the Strategic Hamlet program. "There was an archeology of pacification," Fitzgerald notes, "going back ten, sometimes twenty years. Many of the PF (Popular Forces) outposts . . . had been built by the French for the fathers of those same peasant soldiers."[23] She observes, "For those who stayed in Vietnam long enough, it was like standing on the ground and watching a carousel revolve."[24]

Goal-directed behavior, supported by a memory device (i.e., any facility which allows data from past experience to be stored and held available for recall and later processing[25]), potentially has a better chance of avoiding this "carousel effect" than goal-directed behavior unassisted by a memory capability. By enlarging an entity's data base beyond immediate information to encompass past experiences, memory devices provide a way by which an entity might avoid "endless loop" traps where unsuccessful behavior is continuously repeated. Hence, memory capability renders a goal-seeking entity less sensitive to immediate environmental variations. Of course, depending on the circumstances this can either be beneficial or detrimental. A memory capability would help an army ant colony avoid the endless circling of the "suicide mill," where we are implicitly assuming a relatively fixed environmental context. But, under changing environmental conditions, a memory may not always be beneficial.

The effectiveness of a memory capability depends on the frequency of memory updating and the stability of the relevant variables in an entity's operating environment. An entity in a relatively unchanging environment would need fewer memory updates, than one operating in an unstable one. Unfortunately, static environments don't characterize the world of international politics. International environmental contexts change -- often more frequently than organizations review and update their store of long-term operating principles. In such instances a memory capability can be detrimental. For example, the legacy of the 1950's -- the Communist takeover of China, the Korean War, McCarthyism, Dulles' foreign policies -- has been convincingly invoked as the institutional "memory" which shaped, with disastrous consequences, U.S. Asian policy in the 1960's. Writes James Thomson:

> . . . in 1961 the U.S. government's East Asian establishment was undoubtedly the most rigid and doctrinaire of Washington's regional divisions in foreign affairs. This was especially true at the Department of State . . . It was a bureau that had been purged of its best China expertise, and of farsighted, dispassionate men, as a result of McCarthyism.[26]

A tentative conclusion, then, for goal-directed behavior augmented by a memory capability is that it represents a potentially more sophisticated mode of performance; but, that its actual value, like the notion of goal itself, is strongly context dependent.[27]

SUBGOALS AND DECISION-MAKING HIERARCHIES

Up to this point, we have established general criteria for goal-directed behavior. Further, we have identified some distinctions in goal-directed behavior based upon three kinds of information sources -- environmental, internal, and memory. These criteria were purposefully left abstract enough to embrace different definitional approaches toward goals (e.g., the production system approach, the constraint set approach, the dominant coalition perspective). The goal concept, because of its richness, admits a multiplicity of meanings; hence, at this juncture, it is perhaps more fruitful to treat goals indirectly through characterization, rather than by frontal, definitional assault. Moreover, definitional stipulation, without adequate background preparation, would risk the premature discouraging of future, more promising conceptual approaches towards goals.

Thus far, our discussion on goal-directed behavior has assumed a single goal, unitary entity approach. Under this perspective, such phenomena as multiple goals and switches in goal priorities (i.e., redundancy of potential control) are not readily manageable. Yet, intuitively, these phenomena appear to more accurately characterize the organizational problems of international politics than the single goal, serial processing nature of a servomechanism.

The additional conceptual structure needed to treat multiple goals and redundancy of potential control could, so contend a number of researchers, be provided by the notion of a hierarchy. J. Watkins, for example, argues a proper explanation of seemingly inconsistent behaviors requires the construction of a "hierarchy of dispositions," that is, a hierarchy of goals.[28] Herbert Simon sees hierarchies as the basic framework, the "architecture" of complex systems.[29] Further, preliminary modelling efforts using goal hierarchies have been carried out by Gordon Pask and by Bossel and Hughes.[30]

At the outset, two different hierarchical frameworks must be distinguished -- a hierarchical classification of "adaptive or purposive capability" and a hierarchy of decision-making units. The hierarchy of adaptive or purposive capability arises naturally from the consideration of two tasks which might confront a decision-making entity: goal-setting and goal-seeking. Goal-seeking merely refers to goal-directed behavior. Goal-setting refers to goal-directed behavior where goal changes are possible. Hence, by definition, any entity with a goal-setting capability also has a goal-seeking one. The adaptive capabilities displayed by an entity under various goal-setting and goal-seeking situations give us a rough indication of its decision-making "sophistication." This hierarchy of adaptive capabilities is shown in Table 1. Goal-setting and goal-seeking behavior is subdivided into different situations depending on whether the entity's environment, goal, and behavior remain stable or change. Under these criteria, four distinct goal-setting and four goal-seeking situations are identifiable.

Table 1. Hierarchy of adaptive capabilities

Goal-setting capabilities (goal-directed behavior where changes in goals are possible)

	Goal	Environment	Entity Behavior
1)	changing	stable	changing
2)	changing	changing	changing
3)	changing	changing	stable
4)	changing	stable	stable

Goal-seeking capabilities (goal-directed behavior)

	Goal	Environment	Entity Behavior
1)	fixed	stable	changing
2)	fixed	changing	changing
3)	fixed	changing	stable
4)	fixed	stable	stable < regulating behavior

The goal-setting and goal-seeking distinctions made in Table 1 are on a very high level of abstraction. Goal, environment, and entity behavior changes are all determined relative to some theoretical description which is here left unspecified. Such a description would specify those relevant variables (be they votes, temperature, torque, defense spending, velocity, osmotic pressure and the like) of theoretical interest under the particular analysis in question which define an entity's environment, goal, and behavior. Within this sort of implied framework of identified variables, the environmental, goal, and entity behavior changes in Table 1 refer to the addition or elimination of variables relative to an entity's operating capacity, and not necessarily to every change in a variable's value over time. For example, a temperature change from 75 degrees farenheit to 85 degrees farenheit would not constitute an environmental change for an ordinary home thermostat - i.e., the thermostat's environment over this change is stable. However, a temperature change from 75 degrees farenheit to 6000 degrees farenheit would qualify as an environmental change since the molten remains of the thermostat would no longer be able to monitor temperature change. For all practical purposes, temperature could (at 6000 degrees F) be omitted as a variable relevant to the thermostat's operating capacity. Admittedly, this mode of specifying relevant environmental, goal, and entity behavior changes relative to a given theoretical description is fuzzy; however, the requirements of generality make further precision difficult. Given this understanding of change relative to environments, goals, and behaviors, we now consider some examples of goal-setting and goal-seeking.

Goal-setting clearly is the most sophisticated adaptive capability an entity can have, and is the least understood. No general theory of goal-setting exists. Nonetheless, at least three distinct goal-setting situations can be discerned, some of which are approximated by inanimate systems. The first situation (see Table 1) involves a stable environment where an entity's goal and behavior change. Political situations sensitive to the idiosyncrasies of wavering, uncertain elites serve as examples. The second goal-setting situation involves a changing environment in which an entity's goal and behavior change. Ackoff's hypothetical computer, programmed to play checkers and tic-tac-toe, and designed with a memory updating capability dependent on past games played might serve as an example. In this case, the playing styles of the computer's opponents and game switching between checkers and tic-tac-toe would represent environmental changes. The third goal-setting situation involves a changing environment, a corresponding change in an entity's goal, but unchanging behavior. A crude illustration might involve a nation which maintains a strong army for defensive purposes, then later finds all its external enemies have collapsed; but, nonetheless, continues to maintain its large army for internal domestic and economic reasons. Here, a particular behavior (maintaining a large army) remains unchanged despite environmental changes (disappearance of external enemies) and goal changes (the switch from a defensive military policy to an internal security one). The fourth goal-setting situation entails a change in an entity's goal, but no changes in environment or behavior. A stylized example might involve a gambler at roulette who plays to win, then alters his goal and plays to lose. The gambler's goal switch, in this case, is accompanied neither by an environmental nor behavior change.

Unlike goal-setting, goal-seeking is a less complicated theoretical and design problem, since goal-seeking implies a goal has already been set in some fashion. Hence, each of the four goal-seeking situations in Table 1 can be illustrated using inanimate systems and devices. The first, goal-seeking situation involves a stable environment, a fixed goal, but changing entity behavior. A simple example would be a computer-controlled anti-aircraft system which fires shells at an incoming intruder, fails to down it within a certain time period, and then shifts to a more costly, heat-seeking missile system.[31] A possible, second goal-seeking situation involves a changing environment, a fixed goal, and changing entity behavior. A chess playing computer which modifies its playing on the basis of past games and which always seeks to win could serve as an example. A third goal-seeking situation entails a changing environment, a fixed goal, and unchanging behavior. A missile guided by radar, encountering chaff and then switching to infrared guidance serves as an example. The final, and perhaps simplest goal-seeking situation involves a stable environment, a fixed goal, and unchanging behavior. The regulating behavior of a thermostat falls into this category.

Up to this point, we have examined a hierarchical classification of adaptive capabilities, providing part of the framework which will enable us to treat subgoals. However, another concept of hierarchy, developed by Mesarovic,[32] is necessary for handling subgoals -- a hierarchy of decision-making units. This type of hierarchy requires: (1) the entity under analysis be decomposable into some sort of interacting family of subsystems; (2) all these subsystems exhibit goal-directed behavior; and (3) these subsystems be arranged hierarchically whereby some subsystems are influenced or controlled by others. Again, like our earlier notions of environments, goal-directed behavior, and entity behavior, the concept of a decision-making hierarchy is description dependent. Its character and form depend upon the analytical intent and research interests of the researcher employing this hierarchical perspective.

Taking this notion of a decision-making hierarchy and relating it to our earlier discussion on adaptive capabilities provides a useful framework for discussing subgoals. Each subsystem in a decision-making hierarchy can be thought of as pursuing some goal (however a researcher chooses to define it), which can be considered a subgoal relative to the whole decision-making hierarchy. Moreover, in dealing with systems whose complexity requires hierarchical treatment, subgoals are likely to be of greater analytical use than a single, overall, composite goal representing the whole hierarchy because: (1) a composite goal, in order to capture all contingencies, is likely to be underspecified (e.g., survival, stability, and the like), or (2) if mathematically formulated, is likely to be of as much heuristic value as a specification of some large set, say a dictionary via enumeration.

Having established a decision-making hierarchy, our earlier adaptive hierarchy of capabilities encompassing possible goal-seeking and goal-setting situations can be applied to each subsystem. Hence, each subsystem can be viewed as engaging in some form of goal-setting or goal-seeking behavior. In this sense, the adaptive capability hierarchy is imbedded within the decision-making one. Further, the capability level of each subsystem relative to its subgoal is a rough indication of its "decision latitude." This notion of subsystem decision latitude, in turn, leads naturally to a discussion of the redundancy of potential control phenomenon.

The principle of redundancy of potential control refers, essentially, to the switching of command or control in a system from one location to another. Intuitively, four situations might exist to account for such control switching: (1) subsystems are, in some sense, competing for control over a number of events or trials, and when a subsystem passes a certain information threshold in a given trial it commands until the next trial or event; (2) a single subsystem in a decision-making hierarchy may have the ability to "delegate" temporary control to other lower subsystems in the hierarchy; (3) a fixed, rotation or appointing procedure may exist; or (4) a subsystem may exercise control on its own initiative.

The first, "competitive" interpretation of control redundancy appears closely related to the notion of subsystem decision latitude; that is, the degree of adaptive capability enjoyed by a subsystem. A subsystem, for example, which is so severely constrained structurally, say because it lacks a memory capability, that it can goal-seek only under fixed conditions is likely to be far less successful in "competing" for control than a subsystem which can both goal-seek and goal-set. A political example of control redundancy under competition which stresses the importance of decision latitude concerns the Army's struggle over close air support missions. In the 1950's, the Army, believing the Air Force was neglecting combat support missions in favor of more glamorous strategic ones, began pushing vigorously for responsibility over close tactical air support roles involving helicopters and tactical transports. Eventually, the Army, aided by advances in helicopter technology and the Air Force's inability to satisfy Army needs won significant control over close ground support missions (the Army now has more pilots than the Air Force).[33] Another graphic example of the importance of decision latitude concerns the Navy's development of nuclear armed, carrier based aircraft. To sidestep Congressional and Air Force objections, the Navy simply developed a crude, low budget nuclear delivery system without approval. This fait accompli broke the Air Force's monopoly over nuclear weaponry, and guaranteed Naval control over seaborne nuclear delivery systems.[34]

The second, "delegative" interpretation of control redundancy, whereby a single high level subsystem delegates temporary control to a lower subsystem is illustrated by a naval fleet which follows the commands from the first ship to sight the enemy.[35]

Such authority is delegated by the fleet commander.

The third, "fixed rotation or appointment" interpretation of control redundancy refers to control shifts which are cyclically predetermined so all subsystems eventually have an opportunity to exercise control. A group of children who voluntarily take turns being captain of a baseball team or the rotating chairmanship of the Joint Chiefs of Staff serve as examples.

The fourth, "seizing the initiative," interpretation of control redundancy refers to control shifts arising from a subsystem's exercising of control on its own initiative. Churchill's unauthorized mobilization of the Royal Navy just prior to the outbreak of World War I is an example.

Besides the redundancy of potential control phenomenon, certain other features of subsystems in a decision-making hierarchy deserve mention.[36] First, a higher level subsystem in a decision-making hierarchy will probably have coordination tasks over lower levels, and hence, be concerned with a larger share of overall systems behavior. Moreover, such coordination tasks mean these higher level subsystems have longer decision periods than lower units. The reason -- they cannot act more often than those lower units being coordinated. This, in turn, implies memory capabilities are likely to be more sophisticated on higher rather than lower levels.

A second feature of decision-making hierarchies concerns environmental information. We earlier identified three possible information flows connected with goal-directed behavior: environmental, internal, and memory. The coordination responsibilities of upper decision-making units require a significant dependence on memory and internal monitoring capabilities. However, as Mesarovic notes, "The higher levels cannot respond to variations in the environment . . ., which are faster than the variations of concern to the lower levels, since the latter are reacting faster and more concerned with more particular, local changes."[37] This suggests lower level units, while perhaps endowed with little or no memory capability, are far more sensitive to environmental feedback than upper level units.[38]

A final observation on decision-making hierarchies concerns its possible use for coping with the analytical problem of goal-setting. We noted earlier no general theory of goal-setting exists. However, goal-setting might be conveniently handled by positing a suitable decision-making hierarchy whereby goal-setting on one level is a consequence of goal-seeking on a higher level. Hence, the problem of goal-setting on lower levels is side-stepped by invoking the goal-seeking processes on the next higher level. At the highest decision-making levels the goal-setting problem is avoided by simply positing goals. The justification for such positing comes from assuming: (1) the highest control levels deal with goals requiring long term decision times; (2) such long-range goals will, for a relatively long time span, elicit weak feedback; and (3) over this time span, the highest control levels can be analyzed in isolation without regarding feedback complications -- in particular, goals at these levels can be held constant.[39] Of course, this approach cannot treat goal-setting on all levels concurrently; however, this needn't discourage us. In general, no matter how elaborate any experimental design, certain simplifying assumptions must always be made. Of concern to us is the realism of our assumptions. Holding goals constant at the highest control levels of a decision-making hierarchy is such an assumption, with, as suggested above, much value.

TIME

The notion of goal-directed behavior implies certain things. It implies some entity, possessing an internal processing structure and feedback monitoring capability, to which goal-directed behavior can be imputed. It implies some environment in which the goal-directed behavior takes place. Finally, it implies some notion of time since goal-directed behavior, by its very nature, is concerned with some future state of affairs. Goal-directed entities and their corresponding environments have been treated above. Here, we consider some implications of time for the analysis of goal-directed behavior.

The temporal framework used to study goal-directed behavior can have profound analytical implications. It must be, in some as yet nonrigorously defined sense, appropriate to the phenomena studied. A motivating example demonstrating the importance of the "proper" conception of time arises from a paradox posed by the Greek philosopher, Zeno. According to Zeno's tale, Achilles and a tortise decide, one day, to have a race. Since Achilles can run twice as fast as the tortise, he generously gives the little animal a headstart of distance x. Now, in order to catch up with the tortise Achilles must cover this distance x. But in the time it takes Achilles to cover x, the tortise is moving also and has forged ahead a distance $\frac{x}{2}$. Achilles must cover this additional distance $\frac{x}{2}$ to catch up; however, in the time it takes Achilles to cover $\frac{x}{2}$, the tortise has again moved ahead by a distance $\frac{x}{4}$. In the next action sequence, Achilles covers $\frac{x}{4}$, but the tortise moves ahead again by $\frac{x}{8}$. Since this "catch up" process is a never-ending one, Zeno's conclusion is Achilles never passes the tortise!

The key to this puzzle lies in the way time is framed in the story. Each action sequence of the race, where the momentary positions of Achilles and the tortise are compared, can be thought of as a "snapshot" in time. The first snapshot at the race's beginning, pictures the tortise ahead of Achilles by a distance x, the tortise's headstart. Assume this snapshot is taken at time t. The next snapshot shows the tortise ahead of Achilles by a distance $\frac{x}{2}$. This second snapshot is taken at time $t + \frac{t}{2}$. The third snapshot is taken at time $t + \frac{t}{2} + \frac{t}{4}$, showing the tortise leading by a distance $\frac{x}{4}$. The fourth snapshot is taken at time $t + \frac{t}{2} + \frac{t}{4} + \frac{t}{8}$, the fifth one at time $t + \frac{t}{2} + \frac{t}{4} + \frac{t}{8} + \frac{t}{16}$, and so on. In short, the snapshots of the race are being taken at shorter and shorter time intervals, where the sum of these intervals is a converging, infinite series $(\sum_{i=0}^{\infty} \frac{t}{2^i} = 2t)$. This snapshot sequencing, that is, the way time is being structured, prevents you from seeing Achilles catch the tortise, because an "infinite number" of snapshots would be required. Hence, Zeno's paradox arises, it can be argued, because of the peculiar way time is structured in the story.

Several important lessons can be drawn from Zeno's story. First, time clearly poses an important conceptual challenge in studying goal-directed behavior. As demonstrated by Zeno's paradox, the way time is framed has crucial substantive implications which require close scrutiny. Another example drawn from international relations is Richardson's use of differential equations in his arms race work. These equations imply a continuous time perspective where nations are capable of continuous monitoring and adjustments in arms stocks. The realism of such an assumption is, given such complications as bureaucratic inertia, budgetary cycles, and lead times for weapons development, open to question.

Second, Zeno's story shows time needn't necessarily mean clock time, that is, a continuous flow of seconds, minutes, hours, days, years, and so forth. In fact, for analytical purposes, time is most usefully conceived of as a mode of ordering events or observations. This, in turn, implies time, like goals, is context-dependent and takes on meaning only with respect to a particular description of events. Further, for such a reference system, the time framework or event ordering selected can have a profound impact on the event patterns observed. In Zeno's story, for example, the infinite, converging time intervals ordering observations prevented us from seeing Achilles pass the tortise. If these time intervals had been equal, however, Zeno's paradox would have evaporated, and we would indeed have seen Achilles win the race. Hence, one's time framework must be appropriate, in some intuitive sense, to the research problem under analysis.

Clock time is sufficient for most research purposes; however, it is not always convenient. For example, studies on biorhythm (biological clocks) use physiological processes and cycles for event ordering. Geologists and paleontologists use geologic time measured by decay rates of various radioactive isotopes. Economists sometimes find it useful to order events by fiscal years, economic five year plans, stages of economic growth (à la W. Rostow), and Kondratieff cycles. So far, most of these examples can be translated into clock time with little difficulty. However, this isn't always so. For example, international crisis research frequently uses the notion of response time -- a crisis is identified, in part, as a situation involving low response time for some decision-maker.[40] Unfortunately, response time cannot be equated with clock time because it implies more than temporal duration. First, response time depends on the decision-making skills and processes being studied. What might appear as a low response time situation for one decision-maker might be a high response time situation for another, more skillful one. Second, response time depends on the task being addressed. One hour might be a generous response time for a simple true-false history test, but miserly for a test in partial differential equations. The point here is clock time needn't always be convenient or even appropriate for all research problems.

Since clock time is not suitable in all cases, it is useful to examine other modes of ordering events, related to the structural properties of the phenomena being analyzed. In particular, when considering some entity's goal-directed behavior, potential time frameworks, can be drawn from two basic sources: (1) cycles within or related to the entity's internal processing structure; and (2) the environment's response cycles or patterns, if any, to the entity's behavior.

Often, time frameworks based on an entity's processing structure are conveniently represented by clock time. This is often true for entity's with simple internal processing structure or continuous processing capabilities (e.g., a thermostat). However, other time treatments such as event-based frameworks may be necessary for more involved entities and situations. For example, during the Second World War, some Army Air Corps units automatically rotated bomber crews home after forty missions. Since the time necessary to complete these missions varied from unit to unit, air crews often conceptualized time in terms of missions flown, rather than months served.

Further, if the entity under analysis has a memory capability, the frequency of memory updating or alteration might be used to order events. Governmental upheavals due to elections, coups, purges and the like are some potentially useful examples of such organizational "memory alteration" which might serve as the basis for a time scheme.

The problem of selecting a suitable time framework based on processing structure becomes more complicated when dealing with a hierarchy of decision-making units. Here, suitable time frameworks must be found for all levels of the hierarchy with no guarantee these frameworks will be identical. This, in turn, can lead to problems of comparing different time frames. If, for example, one hierarchical level is best treated using a clock time scheme while another level demands an event-based time framework, the problem of relating these different time frames arises. Unfortunately, such conceptual problems have not yet, in general, been satisfactorily resolved.

Like time frameworks based on an entity's processing structure, those frameworks keying on environment response cycles are often conveniently represented by clock time. For example, after mailing an order to a company, we usually measure response time in terms of days, weeks, or months. In other situations, environment oriented time frameworks may require event-based treatments. A slot machine enthusiast, for example, might measure the length of his Las Vegas visit in terms of number of jackpots won. A more serious example concerns the inflationary spiral generated in 1966 by the Vietnam war. Thinking in terms of fiscal periods, government planners were stunned by the swiftness with which the economy overheated.

Major sectors of the economy, it now appears, roused by events in Vietnam and on Capitol hill, anticipated increased military spending and expanded their activities accordingly even before Federal spending actually penetrated the economy. In short, had the Johnson administration adopted an event time perspective, instead of one based on the fiscal year, timing of the Vietnam war's inflationary impact on the economy might have been more accurately estimated.

So far we have treated separately time frameworks based on entity processing structure and on environment responsiveness. However, it is worthwhile noting the implications of wide discrepancies, when comparison via clock time is possible, between time perspectives based on entity processing structure and environment responsiveness, since such discrepancies can have significant impact on international political theorizing. Before spinning out these implications, a few underlying assumptions will be aired.

First, it will be assumed the use of smaller time units encourages smaller analytical time horizons than the use of larger time units. For example, a person who orders his life's activities in terms of days will probably have a more circumscribed time horizon than one who thinks in terms of weeks or months. Second, it will be assumed the international environment in which nations operate is characterized by long-response times to foreign policy actions. This characteristic was highlighted by Dean Acheson's remark on carpentry as a nice hobby because one needn't wait twenty years to learn the results. Finally, it will be assumed international environmental response times are longer than the cyclic processing times of entity's operating in this international environment.

For cases where these assumptions are accurate, one would expect a time perspective based on entity processing cycles to employ smaller time units than one based on international environment responsiveness; hence, encouraging a smaller analytical time horizon. A nice example is Daniel Ellsberg's argument that U.S. President's, over two decades, knowingly chose a stalemate policy in Vietnam. Ellsberg essentially keys on national elections, the internal processing cycle upon which his analytical time perspective depends, arguing all major escalatory decisions in Vietnam were constrained by the narrow time horizon imposed by election concerns. The result, Ellsberg contends, was a series of short-term, "no win -- no lose," holding actions.[41]

For cases where time perspectives are based on environmental responsiveness, one would expect relatively large time units and, hence, generous analytical time horizons. For example, the Jay Forrester world dynamics model[42] can be thought of as a simulation of environmental responsiveness to nation activities, which employs a longer time horizon than is customary in foreign policy analyses. Indeed, this discrepancy between the time horizon derived from an environmentally-based time framework and the smaller time horizon associated with national processing structures is the key to, what many believe is, the impending collapse of the global social and economic order. Nations, it is argued, tend assiduously to problems sharply localized in time while global disasters, unfolding within a larger temporal context, threaten to engulf everyone.

These examples hopefully demonstrate the theoretical importance of time frameworks for evaluating goal-directed behavior. Certainly, no single time framework is inherently superior. The appropriateness of a given time perspective must be judged on a case-by-case basis. Hence, full disclosure of temporal assumptions is important. In particular, an explicit conception of time must be a part of any theory of politics, especially if time is defined in terms of entity processing or environmental cycles. Only then can one's time framework be evaluated for its analytical appropriateness.

SUMMARY

We began our examination of the goal concept in international relations research by considering its role in theorizing. Goals and goal-directed behavior are working assumptions which reflect the posited regularity or underlying order of events in international relations upon which theorizing depends. Further, we identified two analytical strategies, posited preference and revealed preference, by which goal-directedness contributes to international relations theorizing.

After considering the analytical utility of goals, we briefly surveyed its past use in international relations research. While no consistent approach towards goals emerged from our survey, certain key themes and issues were discernible such as the linking of goals to organizational processing and structure, the notion of subgoals and switches in goal priorities, and the relationship of time to goals.

Next, to provide the necessary analytical background for treating these issues, we turned our efforts towards developing criteria for goal-directed behavior, avoiding the danger of prematurely specifying a single goal definition. It was then argued goal-directed behavior might be usefully characterized by two conditions: (1) some goal notion (left unspecified here) and attendant theory causally linking an entity's behavior and its goal, and (2) some feedback loop connecting the entity's processing structure to its environment. We further noted the potential advantages of goal-directed behavior backed by memory and internal monitoring capabilities.

Two notions of hierarchies, a hierarchy of adaptive capabilities and a hierarchy of decision-making units, were introduced. The hierarchy of adaptive capabilities aided us in distinguishing between different goal-setting and goal-seeking situations. The hierarchy of decision-making units provided a conceptual framework for discussing subgoals, the notion of redundancy of potential control, goal-setting, and goal-seeking.

Next, the problem of time was raised. First, we argued clock time isn't always analytically appropriate for treating goal-directed behavior. Second, in cases where clock time proves inappropriate, two alternative sources for structuring time were examined: (1) cycles or patterns related to an entity's internal processing structure, and (2) the environment's response cycles, if any, to the entity's behavior. Finally, the implications of differing time horizons arising from wide discrepancies between these two time perspectives were examined. Throughout this discussion, the context-dependent nature of time relative to the particular issue under study was stressed, thus re-emphasizing the description-dependent nature of goal-directed behavior in general.

FOOTNOTES

[1]William Riker and Peter Ordeshook An Introduction To Positive Political Theory (Englewood Cliffs, Prentice-Hall, Inc., 1973) p. 10

[2]John Gunnell "Social Science and Political Reality: The Problem of Explanation" Social Research, Vol. 35, No. 1 (Spring, 1968), p. 196.

[3]Herbert Simon The Sciences of the Artificial (Cambridge, MIT Press, 1969), p. 8.

[4]Riker and Ordeshook, p. 14.

[5]Graham Allison Essence of Decision (Boston, Little, Brown, and Co., 1971) p. 33.

[6]Ernst Haas and Allen Whiting Dynamics of International Relations (New York, McGraw-Hill, 1956), p. 59-69.

[7]Donald Puchala International Politics Today (New York, Dodd, Mead, 1971).

[8]See S.J. Thorson and R.A. Miller "Optimization and Arms Races: A Model Theoretic Analysis" (Columbus, Ohio State University, 1975) for an extended discussion of the theoretical implications of constructive specification. See also Mihajio Mesarovic, "General Systems Theory and its Mathematical Foundation" (Case Western Reserve University, 1967).

[9]For an overview of research on international organizations, see Chadwick Alger "Research on Research: A Decade of Quantitative and Field Research on International Organizations," International Organization, Vol. XXIV, No. 3 (1970), pp. 414-450.

[10]Patrick McGowan "Toward A Dynamic Theory of Foreign Policy" (Syracuse, Maxwell School, Syracuse University, 1971). See also Patrick McGowan, "Adaptive Foreign Policy Behavior: An Empirical Approach" in James Rosenau (ed.) Comparing Foreign Policies (New York, SAGE Publications, Inc., 1974) pp. 45-54.

[11]The automatic, semi-automatic, and manually operated system questions on Kaplan's essential rules were initially raised by Inis Claude about Kaplan's "balance of power" system. However, such questions of interpretation can, in general, be lodged against all of Kaplan's models. See Morton Kaplan, System and Process In International Politics (New York, John Wiley & Sons, Inc., 1957), pp. 3-53. See also Inis Claude, Jr., Power and International Relations (New York, Random House, 1962), pp. 47-48.

[12]For discussions of the Parsonian approach to systems see Talcott Parsons, The Social System (New York, The Free Press, 1951); Structure and Process in Modern Societies (New York, The Free Press, 1960); and "An Outline of the Social System," in Parsons, et al., eds., Theories of Society (New York, The Free Press, 1961).

[13]For a more detailed treatment of production systems see Paul Anderson, "The Role of Complete Processing Models In Theories of Inter-Nation Behavior" (Ohio State University, Project for Theoretical Politics Research Report 28, 1974).

[14]As an interesting aside related to the production system's imbedded goal structure, Pask argues any system for which a cybernetic theory can be constructed must, of necessity, have some goal "built" into it. See Gordon Pask, "The Cybernetics of Behavior and Cognition Extending the Meaning of 'Goal'" Cybernetica, Vol. XIII, No. 3, 1970, p. 150.

[15]Herbert Simon "On the Concept of Organizational Goal" Administrative Science Quarterly, Vol. 9, No. 1 (June, 1964), pp. 1-22.

[16]James Thompson Organizations In Action (New York, McGraw-Hill, 1967), p. 128.

[17]Linda Brady "Goal Properties of Foreign Policy: Professed Orientation To Change and Goal Subject" (Vanderbilt University, CREON Project, 1974).

[18]Stuart Thorson "Modeling Control Structures For Complex Social Systems" (Ohio State University, Project for Theoretical Politics, 1974), pp. 3-6.

[19]Sommerhoff suggests three conditions for goal-directed behavior: (1) the goal pursued must be contingently possible, (2) system outputs or actions musn't be causally related by environmental variables; that is, the realization of goals must be achieved by the system, and (3) observed, goal-directed system behavior would have been appropriately modified to achieve the goal, if environmental conditions had differed from those actually observed.

The latter two conditions seem acceptable; but, the first condition, demanding contingent possibility, can be questioned. History abounds with explorers seeking nonexistent cities or continents (e.g., the Spanish search for the fabled Seven Cities of Cibola, the British search for a rumored southern Pacific continent, the search for a Northwest passage). Intuitively, one would like to call these searches goal-directed. Hence, in this paper, Sommerhoff's first contingent possibility condition is dropped. See Gerd Sommerhoff, Logic of the Living Brain (London, John Wiley & Sons, 1974), pp. 16-25.

[20]The relative, context dependent nature of purposes was clearly recognized by Rosenblueth and Wiener. They wrote:

> We believe . . . that the notion of purpose is not absolute, but relative; it admits degrees. We further believe that it involves a human element, namely the attitude and objective of the observer. Different observers may well differ in their evaluation of the degree of purposefulness of a given behavior. And the same observer may study a given behavior as purposeful or purposeless, with different objectives. But these limitations of the notion of purpose are common to many other scientific categories, and do not detract from their validity and usefulness. Arturo Rosenblueth and Norbert Wiener, "Purposeful and Non-Purposeful Behavior," in Modern Systems Research for the Behavioral Scientist, ed. by Walter Buckley (Chicago, Aldine Publishing Company, 1968), p. 235.

[21]Thorson, "Modeling Control Structures," p. 3.

[22]Karl Deutsch, The Nerves of Government (New York, The Free Press, 1966), p. 129.

[23]Frances Fitzgerald, Fire In the Lake (New York, Vintage Books, 1972), p. 453.

[24]*Ibid.*, p. 453.

[25]As used here, a memory refers to the capacity for storing and retrieving past experiences which the entity has reacted to in some fashion. Data which has initially been "wired or designed" into an entity at inception as part of its processing structure would, therefore, not be considered a product of memory since this data did not arise from the entity's past operating experiences. So, for example, the digital map which is programmed before launch into the military's Terrain Contour Matching missile guidance system would not constitute a memory, as defined here.

[26]James Thomson "How Could Vietnam Happen? An Autopsy," in Readings In American Foreign Policy, ed. by M. Halperin and A. Kanter (Boston, Little, Brown and Company, 1973), p. 99.

[27]The context dependent nature of memory, and indeed of organization in general, also holds in a biological context as demonstrated by W. Ross Ashby:

> Is it not good that a brain should have memory? Not at all, I reply -- only when the environment is of a type in which the future often copies the past; should the future often be the inverse of the past, memory is actually disadvantageous. A well known example is given when the sewer rat faces the environmental system known as "pre-baiting." The naive rat is very suspicious, and takes strange food only in small quantities. If, however, wholesome food appears at some place for three days in succession, the sewer rat will learn, and on the fourth day will eat to repletion and die. The rat without memory, however, is as suspicious on the fourth day as on the first, and lives. Thus, in this environment, memory is positively disadvantageous. Prolonged contact with this environment will lead, other things being equal, to evolution in the direction of diminished memory-capacity.
> W. Ross Ashby, "Principles of the Self-Organizing System," in Modern Systems Research for the Behavioral Scientist, ed. by Walter Buckley (Chicago, Aldine Publishing Company, 1968), pp. 112-113.

[28]J.W.N. Watkins "Ideal Types and Historical Explanation," in The Philosophy of Social Explanation, ed. by Alan Ryan (Bristol, England, Oxford University Press, 1973), p. 101.

[29]Herbert Simon "The Sciences of the Artificial" (Cambridge, MIT Press, 1969), pp. 84-118.

[30]See Gordon Pask, "The Cybernetics of Behavior and Cognition Extending the Meaning of 'Goal'," Cybernetica, No. 4, Vol. XIII (1970), pp. 247-248. See also Hartmut H. Bossel and Barry Hughes, Simulation of Value-Controlled Decision-Making: Approach and Prototype (Karlsruhe, Federal Republic of Germany, Institut fur Systemtechnik und Innovationsforschung, August, 1973).

31 Another, less militaristic example, cited by Ackoff, involves an electronic maze-solving rat (a simple automata) which, when blocked by a wall in maze, moves in a programmed sequence of ways until an open path is found. The sequence is such that it can solve at least some solvable mazes. If this rat has a memory device, it can also be programmed to take a "solution path" on subsequent trials in a familiar maze. See Russell Ackoff and Fred Emery, On Purposeful Systems (New York, Aldine-Atherton, 1972), p. 31.

32 M.D. Mesarovic, D. Macko, and Y. Takahara Theory of Hierarchical, Multilevel, Systems (New York, Academic Press, 1970), pp.49-56.

33 See Morton Halperin Bureaucratic Politics and Foreign Policy (Washington D.C., Brookings Institution, 1974), pp. 43-46.

34 See Vincent Davis "The Development of a Capability to Deliver Nuclear Weapons by Carrier-Based Aircraft," in Readings In American Foreign Policy, ed. by M. Halperin and A. Kanter (Boston, Little, Brown, and Company, 1973), pp. 261-275.

35 Thorson "Modelling Control Structures," p. 5.

36 These characteristics are taken from Mesarovic. See Mesarovic, Macko, and Takahara, pp. 54-56.

37 Ibid., p. 55.

38 Stories of "men in the field" (i.e., lower level units of some decision-making hierarchy) who develop a greater sensitivity for their local areas than the people back at the "home office" (i.e., upper level units) are legion. More interesting are the tales of actual "memory suppression" on lower levels. Consider, for example, the plight of a military officer assigned to the Defense Intelligence Agency (DIA) during the Vietnam era:

> He knows or soon learns that he will be thrust into a position in which, on occasion, his professional judgment will vary markedly from that of his parent service. He will be expected to defend a position that could enrage his Chief of Staff -- but officers who do so more than once get known fast and are accorded an appropriate "reward" at a later date in terms of promotion and assignment. Consider also that a tour at DIA -- normally two to three years -- a very short when compared to a 20- to 30-year military career. And so most officers assigned to DIA go through a predictable pattern. They come on board as "hard-chargers," ready to set the world on fire. They stick to their principles through one or two scrapes. Then they become a little more circumspect, letting individual issues slide by and rationalizing that it wasn't a crunch question anyway. Finally, they resign themselves to "sweating out" their tours and playing every situation by ear. They avoid committing themselves or making decisions. They refuse to tackle the agency's long-term organizational ills, because doing so would make too many waves.

Patrick McGarvey, "DIA: Intelligence To Please," in Readings in American Foreign Policy, ed. by M. Halperin and A. Kanter (Boston, Little, Brown, and Company, 1973), p. 325.

[39]The assumptions listed here are derived from the work of Simon and Ando on decomposability and aggregation of systems. One of their theorems (as interpreted by Crecine) implies: if feedback is weak, there exists a time span over which a system can be analyzed in isolation without regarding feedback complications. The time span over which this analysis is valid depends on the weakness of the feedbacks. See J. Crecine, Governmental Problem-Solving: A Computer Simulation of Municipal Budgeting (Chicago, Rand McNally, 1969). See also A. Ando, F. Fisher, and H. Simon, Essays on the Structure of Social Science Models (Cambridge, MIT Press, 1963).

[40]James Robinson "Crisis: An Appraisal of Concepts and Theories," in International Crises: Insights From Behavioral Research, ed. by Charles Hermann (New York, The Free Press, 1972), pp. 23-25.

[41]Daniel Ellsberg Papers on the War (New York, Simon and Shuster, 1972), pp. 42-135.

[42]See Jay Forrester, World Dynamics (Cambridge, Wright-Allen Press, 1971).

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WORKING DRAFT

Governments As Information Processing Systems:

A Computer Simulation*

Stuart J. Thorson
Polimetrics Laboratory
Department of Political Science
Ohio State University

Paul A. Anderson
Department of Political Science
Ohio State University

Esther Thorson
Department of Psychology
Denison University

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Research Paper No. 37

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GOVERNMENTS AS INFORMATION PROCESSING SYSTEMS: A COMPUTER SIMULATION

Stuart J. Thorson
Polimetrics Laboratory
Department of Political Science
Ohio State University

Paul A. Anderson
Department of Political Science
Ohio State University

Esther Thorson
Department of Psychology
Denison University

§ 1 INTRODUCTION

The purpose of this paper is to describe a computer simulation based project designed to elucidate the mechanism by which national governments obtain and process information about their environments and produce behaviors which are sent back to their environments. The procedure will then be to perform experiments on these simulations. More specifically, this report will discuss a preliminary version of a large scale simulation of Saudi Arabian decision making with respect to such domestic policy areas as oil, agriculture, and human resources. Following a treatment of the simulation in its present status, problems of evaluating, validating, and modifying the simulation will be examined. First however it is necessary to outline briefly the methodological perspective from which the simulations are being developed.

Within the field of international politics a number of scholars have begun to employ concepts rooted in "systems theory" to develop theories of governmental behavior (e.g., see Kaplan, 1957; Rosenau, 1970; Forrester, 1971; McGowan, 1974; Phillips, 1974; Thorson 1974a). Most all of these researchers comment on the relative "complexity" of international politics and the variety of difficulties this complexity poses for the theorist. As examples, it is likely that any reasonable theory would have to include a fairly large number of variables; that the relations between these variables may often not be simple linear ones; and that there are fairly long time delays operating with the international system. Such characteristics naturally suggest a computer simulation approach to the modeling of governmental decisionmaking.

While the above list of "complexities" is suggestive, it is nowhere near complete enough to restrict usefully the class of admissible models of governments. Yet the basic motivation behind any kind of experimentation - be it simulation based or otherwise - is to use prior knowledge. Quite obviously, the more detailed the prior knowledge, the more detailed will be the knowledge generated through a well-designed experiment. Equally obviously, it is generally easier to design optimal experiments (optimal here is being used in the sense of Federov, 1972) in situations where the store of relevant prior knowledge is large. A basic problem in macro-level modeling of governmental decision making is that available knowledge is neither detailed nor abundant.

The design of experiments must not only take into account available knowledge; it also requires a clear specification of the research question(s). At an abstract level two kinds of experiments can be distinguished. The first kind, sometimes termed "extremal experiments," is employed to answer questions concerning the conditions under which the structure being investigated will satisfy some optionality criterion. Thus it might be asked under what conditions a government will allocate its resources among domestic and international expenditures in such a way as to maximize some aggregate utility function. Elsewhere (Miller and Thorson, 1975a, b) it has been argued that not enough is yet known about governments to perform extremal experiments in a useful way. The reasoning behind this claim hinges on the dependence of most conditions of optimality (under most any usual sense of optimality) upon certain very finely grained (detailed) hypotheses (e.g., continuity, existence of second derivatives, etc.) being true of the world.

A second mode of experimentation has been called "mechanism-elucidating experiments" (Federov, 1972, pp. 3-6). Here the interest is more in the "global" behavior of the structure. That is, the task is to investigate implications of possible functional relations between input and output variables. Mechanism-elucidating experiments appear to be appropriate where existing theory is weak or nonexistent and where the purpose is to develop theory. The simulations reported on in this paper are being designed to be used in mechanism-elucidating experiments. Problems of validating such simulations will be discussed in a later section.

As was mentioned earlier, the design of any experiment derives from an attempt to exploit existing knowledge to suggest new knowledge. Therefore it is important to summarize the broad "operating characteristics" or "principles" which any structure posited as a possible model of a government must have. These properties may be viewed as properties necessary to any structure claimed to be a model of government. While the properties individually seem quite reasonable, there are few existing models which simultaneously satisfy all of them. Since these principles are discussed elsewhere, they will briefly be motivated and reference will be made to sources for further justification.

Even casual observers of politics are frequently struck with the changing and often apparently adaptive nature of national policy behaviors. International alliances seem to shift in apparent response to changing "realities" such as a perceived scarcity of oil. Yet, as with most all adaptive mechanisms, the range of adaptation has limits. Some policies (U.S. policy towards China would serve as an example) change very slowly and the reasons for the slow change seem related more to the internal structure of the mechanism itself (e.g., bureaucratic and individual level "politics") than to the external environment the government is attempting to handle.

Taken together, these observations suggest several principles. First, and of considerable importance, governments must be modeled as control structures operating in specific external environments. That is, governments attempt to manipulate specific external environments. No claim is made that governments are optimal control mechanisms. Further support for this claim can be found in Rosenau, 1970; Rosenau, 1974; and Thorson, 1974a. A well-known example of an attempt to model international behaviors without viewing governments as control structures is found in Forrester, 1971.

Second, the internal structure of the government must be explicitly modeled. In systems terms, the output of the governmental control structure will be a function (in the mathematical sense) of the inputs and the current state of the government. There is considerable evidence to suggest that assessing the state of the governmental structure requires at least the modeling of bureaucratic structures within the government. Empirical support for this claim is found in Allison, 1971; Halperin and Kanter, 1973; and Halperin, 1974. Much of the arms race modeling effort (e.g., Brito, 1972) violates this principle and considers the government as a "unitary rational actor."

Third, internally governments are organized hierarchically. In other words, there is a large degree of specialization within a government. Different kinds of information and decisions are processed at different levels of the hierarchy. Support for this assertion is found in Phillips, 1974; Anderson, 1974; Mesarovic and Pestel, 1974; and Nurmi, 1974. Again, most arms race models and the Forrester WORLD2 model violate this principle.

Fourth, governments pursue multiple (and sometimes conflicting) goals. This principle is related to the previous principle, and support for it can be found in the same sources. While this claim seems most reasonable, there are some technical reasons (Miller and Thorson, 1975b) why this principle may need to be modified. Nonetheless, it has guided the modeling effort reported in this paper.

Fifth, governments exhibit redundancy of potential control. According to Arbib (1972, p. 17) the principle of redundancy of potential control "states, essentially, that command should pass to the region with the most important information." As an illustration Arbib (who attributes the example to Warren McCulloch) cites "a World War I naval fleet where the behavior of the whole fleet is controlled (at least temporarily) by the signals from whichever ship first sights the enemy, the point being that this ship need not be the flagship, in which command normally resides (p. 17)." The critical point here is that potential control need not reside in only one portion of a government. Indeed the way in which various governments resolve the redundancy is critical to understanding and explaining its behavior. Current attempts by the U.S. military to upgrade its command, control, and communications "systems" reflects an implicit recognition of the redundancy notion within one bureaucracy. Moreover, important decisions (e.g., whether to sell a sophisticated weapons system to some country) generally involve more than one bureaucracy at more than one level of the hierarchy. We could find no existing models which have the redundancy property.

Sixth, governments are event-based (that is, governments respond to events in the external environment). These events may have associated with them particular probability distributions. Thus long-range forecasting (though not policy planning) may be very difficult. Moreover the notion of time employed in the model should be "event time," that is, the "time flow" against which the system states are plotted should be event based. This suggests, for example, that differential equation models are either inappropriate or require considerable reinterpretation. The arms race models and the Forrester model are inconsistent with this principle. Crecine, 1969, provides evidence for the event-based nature of governmental structures. See Miller and Thorson, 1975b, for a more detailed discussion of this and the next point.

Seventh, models of governments must allow for disturbances. The environment in which governments operate is noisy, and random disturbances may be important in "defining" the events to which governments respond. The presence of disturbances is especially important to recognize if external experiments are to be designed.

The seven principles outlined above serve as framework conditions within which the simulation to be designed below is being developed. Basically, the domestic portion of the Saudi Arabia simulation is divided into three external environment models: an agriculture module, an oil module, and a human resources module. A fourth module, the decision module, serves as a model of the governmental control structure. These simulations are being developed in interaction with policy planners in the State and Defense Departments (see Phillips and Thorson, 1974 for a description of the interaction). In this paper the focus will be on the decision and the agriculture modules.

§ 2 OVERVIEW OF THE SIMULATION

Any attempt to model a government using a computer simulation must address two points: 1) What are the structural characteristics of a government; and 2) How is the structure to be implemented as a computer simulation? The first point deals with the nature of that which is simulated. The second, with its realization as a computer program.

The basic characterization used to structure the nature of governments is expressed in one of the organizing principles discussed above: Governments are goal seeking systems. But to simply state that governments are goal seeking systems does not provide sufficient structure to allow machine implementation. Additional structure is required. The additional structure imposed upon the characterizations of governments is illustrated in Figure 1. The basic elements of this structure are: 1) the government (or inner environment); 2) the outer environment (the process to be controlled); 3) the observation interface; 4) the access interface; and 5) the model of the outer environment. (Cf. Simon, 1969; Thorson, 1974). Under this interpretation, governments take observations of the current state of the outer environment. Based upon those observations, the government, with the use of the image of the causal operation of the outer environment, generates outputs (access interface actions) that are intended to increase the level of goal achievement.

In the Saudi Arabian simulation presented here, the inner environment, access interface, and observation interface are all parts of the Saudi bureaucracy. The environment can be usefully partitioned into two classes, the domestic and international environments. In the simulation, the domestic environment has been additionally decomposed into three sectors: oil, agriculture, and human resources. Each of these three components are simulations in their own rights. The oil module models oil production and petroleum revenue, the agriculture module models the production of wheat, and human resources models the flow of people in Saudi Arabia from the perspective of education and employment. Thus on one level, the decision module attempts to control these three domestic environments so as to achieve a set of goals. In addition, the government of Saudi Arabia has goals for the international environment. The entities in the international environment consists of other nations, e.g., Iran, Egypt, Israel, the United States, governmental organizations, e.g., OPEC, the Arab League, the PLO, and the UN, as well as non-governmental actors, e.g., ARAMCO. In this report, the only portion of the simulation to be discussed in any depth will be the agriculture module (the environment) and the portion of the decision module with primary responsibility for controlling it (the Saudi Ministry of Agriculture).

Even with a characterization of that which is to be simulated, and the organizing principles constraining admissable solutions, there is still the question of implementation. Since the construction of the simulation is an effort at elucidating the internal mechanism by which governments generate behaviors, the manner in which the model is represented as a computer program is consequential. In the area of computer simulations of human problem solving, similar concerns have been expressed. Allen Newell (1973a) developed the notion of control structure as a means for addressing this point. The control structure of a model is roughly the system architecture. The control structure specifies how the basic processes of the model are organized into a coherent whole. The control structure is in part determined by the programming language used.

> A language such as FORTRAN (or any other, for that matter) may be seen as a device to evoke a sequence of primitive operations, the exact sequence being conditional upon the data. The primitive operations in FORTRAN are the arithmetic operations, the given functions ..., the assignment of a value to a variable, the input and output operations, etc. Each of these has a name in the language (+, -, SIN, LOG, etc.). However, just having the names is not enough. Specifying the conditional sequence is also required and what does that is called the control structure. In FORTRAN it includes the syntax of algebraic expressions, ... the order of statements ... the syntax of the iteration statement, ... the format of the conditional and unconditional branch. (Newell, 1973b 297)

For some purposes it is acceptable to let the programming language determine in large part the control structure. Other times contraints such as minimum execution time, or minimum storage requirements will help determine how the control structure is realized. But if one wishes to make a theoretical statement using the structure of the program itself, those solutions are not acceptable, since such solutions contain implicit but inadmissable theoretical claims. The programming technique (and control structure) that is used for the decision module is called a production system. Since the intent is only to theorize about governments, PL/1 has been used for programming the oil, agriculture, and human resources simulation module. Newell developed this programming structure for the simulation of cognitive processes. While the operation of production systems will be discussed in more detail below, several comments are in order. The first is that all operators, other than the basic flow of control in production systems must be explicitly defined. Second, programs structured as production systems do not result in the minimization of program coding time, execution time, or storage requirements. There exist "easier" methods for coding a program to produce similar outputs. But these other ways to program the decision module have the potential for introducing methods and processes that do not reasonably reflect the structure or capability of the processing mechanism of governments. Given the basic flow of control inherent in production systems, it was necessary to define only one additional operator, the ** operator discussed below. This method for structuring the decision module has the advantage that the claims about the information processing capability of governments are explicit. Any assumptions about the capability of governments to process information had to be explicitly defined. Thus the chance of making unintentional capability claims as a result of the way in which the decision module was programmed have been minimized.

Processing models written as production systems are formed by a collection of independent rules, called productions. The rules (or productions) are stated in the form of a condition and an action: C → A. The condition refers to the symbol in the short-term image (STI) of the system. The STI represents the system's transient image of the current state of the OE. The actions of the productions consists of transformations on the STI "including the generation, interpretation, and satisfaction of goals, modification of existing elements, and addition of new ones." (Klahr, 1973:528) A production system obeys simple operating rules:

i. The productions are considered in sequence, starting with the first.
ii. Each condition is compared with the current state of knowledge in the system, as represented by the symbols in STI. If all of the elements in a condition can be matched with elements (in any order) in STI, then the condition is satisfied.
iii. If a condition is not satisfied, the next production rule , the ordered list of production rules, is considered.
iv. If a condition is satisfied, the actions to the right of the arrow are taken. Then the production system is reentered from the top (Step i).
v. When a condition is satisfied, all those STI elements that were matched are moved to the front of STI.
vi. Actions can change the state of goals, replace elements, apply operators, or add elements to STI.
vii. The STI is a stack in which a new element appears at the top pushing all else in the stack down one position. Since STI is limited in size, elements may be lost. (from Klahr 1973:528-29)

Prior to a discussion of the production system for the Saudi Ministry of Agriculture in detail, the basic operation of the module will be discussed. After the operation of the system has been discussed in a verbal fashion, a portion of the production system will be discussed in detail as a production system.

As discussed above, a number of organizing principles have been employed as constraints on admissable solution to the construction of a simulated government. Not all of those principles are directly reflected in that aspect of the decision module which roughly corresponds to the Saudi Arabian Ministry of Agriculture presented here for several reasons. In particular, the principles of hierarchical organization, redundancy of potential control, and multi-goal seeking are not represented because the simulation module as represented here is only a portion of the total structure. In addition, since the decision module is a developmental version, the decision making properties of the module are at a relatively primitive state. In spite of these shortcomings, the module, as presented above, does serve as a useful illustration of the basic technique and its potential.

In essense, the decision module can be conceptualized as attempting to improve performance as indexed by a function with two arguments: yield = f(fertilizer constraint on yield, mechanization constraint on yield). Within the agriculture module, the yield at any given point in time is a function of the level of fertilizer application and mechanization usage. The fertilizer constraint on yield can be expressed as follows: given the current level of fertilization, assuming all other factors are optimal, what is the maximum possible yield? The mechanization constraint has a similar expression Since the actual yield will be constrained by the smallest constraint, if yield is to be increased, the lesser of the two constraints must be increased. The policy variables open to the government, under this interpretation, are the amount budgeted for governmental fertilizer purchase, and the amount budgeted for governmental provision of tractors.

Assuming that the Saudi's budget is increasing, the motivation for the resultant governmental output is as follows: Assume there is more money to spend, the constraint is (say) fertilizer, and the desire is to raise yield. More money should be spent on fertilizer and the same amount on mechanization. Mechanization could be decreased since some money spent on mechanization is wasted, but since it is not known exactly how the mechanization constraint behaves with respect to budget levels and since money is "cheap" and decreased yields are "costly" it is more prudent to take the chance of "wasting" some money by spending more on fertilizer to improve the chance of increasing yield.

From a more operational perspective, it is required that governments make observations of the environment and base outputs upon those "perceptions" of the current state of the outer environment. As a result, inputs into the decision module are statements describing the current mechanization and fertilizer constraints on yield as being very high, high, moderate, low, and very low. These descriptions of the constraints are determined according to the scale in Figure 2. An inspection of Figure 2 shows the scale not to be an equal interval scale. Judgments between high and very high represent finer distinctions than does a judgment between high and moderate. This scale and the use of an ordinal description of the outer environment is based on two assumptions: The first is that the Saudi government does not have the information processing capacity to handle (nor the measurement sophistication to use) finer distinctions. The second is that the Saudi's are capable of making relatively finer distinctions at the extremes of the scale. This claim about the capability of the Saudi's to process information is supported by by Al-Awaji's (1971:147) description of the planning system as "institutionally fragmented and substantially ineffective," the lack of qualified manpower to staff the Saudi bureaucracy (Al Awaji, 1971:218), and the fact that as of today, there still has not been a thorough census of the Saudi population.

Based upon the absolute judgments of the constraints, the decision module makes a comparison between the two constraints, resulting in relative statements such as: "The fertilizer constraint is much greater than the mechanization constraint." This comparison is also based upon the scale in Figure 2 and reflects the fact that judgments are more fine grained at the extremes of the scale. One constraint is higher than another if a "boundary," i.e., the cutoff point between high and medium, is crossed. For example, a very high constraint is judged greater than a high constraint, and a high constraint is judged greater than a medium constraint. If two "boundaries" are crossed, the comparison is that of very high. Thus, a very high constraint is very much greater than a medium constraint, and a medium constraint is very much higher than a very low constraint. If more than two boundaries are crossed, the comparison is 'much greater than'.

These two rankings of the constraints serve as the basic input to the choice portion of the production system. The structure of the decision module breaks the process of generating outputs into two portions. First the budget to be manipulated is determined, e.g., budget for fertilizer purchase, and/or budget for tractor purchase. Secondly, the amount of change in the budget's selected (increase a little, increase, increase a lot) is determined. The decision module uses the first relative judgment (greater than) to determine which budget to manipulate. If one constraint is less than the other, the lowest constraint is chosen. If both constraints are "about the same," both budgets are increased. If the budget to be increased has a high or very high constraint, the budget is increased "a little." If the constraint is medium, the budget (or budgets) is simply "increased." If the level of the constraint is low or very low, the budget is increased "a lot."

In the current implementation of the decision module, increase a little means to increase the budget by 20%, increase means increase the budget by 50%, and increase a lot means to increase the budget by 150%. Since the actual budget changes will in the final analysis be determined by the Council of Ministers, the current procedure represents only a temporary method for allowing a portion of the decision module to operate for testing purposes. The rates of increase should not be taken too seriously. In addition, the portion of the module discussed above assumes no budget decrease takes place.

A Production System Example

In light of the above discussion of the rules upon which a production system operates, and the non-technical (from a programming point of view) discussion of the operation of the module, the portion of the agriculture module in Figure 3 should be fairly straight forward. The system in Figure 3 is that portion of the production system that takes the judgments of the size of the constraints and determines which budgets to increase and by how much they should be increased.

As mentioned above, there is only one operator that was implemented, the ** operator. The ** operator takes the first element in the short term image (STI) and replaces it with the double stars. Thus, if the ** expression were: OLD(**) and the first element in the STI where $$$$$, then after the execution of the **, the front of STI would be: OLD($$$$$). This operator was necessary to insure that the system would not go into an endless loop. If a production were satisfied by the elements of STI, after the operation of the ** operator, the production would not be executed again, until the masked condition were reentered into STI.

As an example, consider the operation when the STI contains the symbols YMECH MEDIUM,YFERT GREATER THAN YMECH. The system starts with production 1. Since the conditions of production 1 are not in STI, the system checks production 2. This process continues until production 12 is executed. The elements in STI match the conditions of the production, and the action portion of the production is executed. This results in 1) the elements in STI that matched the production conditions being placed in the front of STI; 2) the ** operator is applied to the first element in STI, YFERT GREATER THAN YMECH. The result is that OLD(YFERT GREATER THAN YMECH) is now the first element in STI; 3) the symbol string INCREASE BMECH A LOT is placed in the front of STI, moving all other symbol strings down one position; 4) control is passed to the first production. The system loops through the productions until none of the productions is satisfied. At that point control passes to the portion of the module responsible for taking these qualitative changes in the budgets and producing actual budget figures.

The agriculture decision module presented here serves only as a preliminary version upon which more sophisticated and reasonable modules can be based. Besides the obvious necessity of addressing the question of the validity of the simulations (discussed below), the next path for future development are in two main areas. The first is the development of the processing sophistication of the decision module; for example the necessity to model learning within the bureaucracy. But in its present form, no learning takes place in the decision module. In addition, the implicit model of the environment the module is attempting to control is made up of monotonically increasing functions. For example, the decision module implicitly assumes that the yield function always increases with increased levels of the relevant variables. Thus, from the perspective of the decision module, if 2 kilograms of fertilizer per hectare are good, 200000 kilograms of fertilizer will result in even better yields. The second class of sophistication that is planned for the decision module is that of language processing. The quality of language processing becomes especially important when dealing with the international aspects of the outer environment. Diplomacy is in many respects a linguistic exercise. The capability for language processing entails that outputs from the simulations be sentences in a language. For the simulation to have this capability, several things are necessary. First the language and its associated grammar must be specified. Secondly, the routines must be written which will take sentences describing either states of the environment or actions of other actors as input and produce perceptions of the current level of goal achievement to serve as inputs into the decision making portion of the system.

§ 3 VALIDATION

Since a simulation approach was adopted out of a concern for explicitly modeling the complexity of international politics, the validity of the simulation is very difficult to assess. Nonetheless, it seems clear (at least in a "lessons learned" sense) that large scale social simulation efforts must be continually concerned with validity issues (e.g., see Brewer, 1974). The discussion of validation problems provided in Hermann, (1967) is a very useful summary of the issues involved. Rather than repeat his points, this discussion will focus on problems specific to the "production system" approach described above and to the concern for doing mechanism elucidating experiments. If the research questions necessitated (and at some point they will) extremal experiments, then it would be critical to consider the problem of construct validity much more than has been done thus far. Ideally, each variable in the simulation would have several converging measures or indicies. If observed values of a particular measure of a certain variable can be used to predict to observed values of other measures of the same variable, confidence is increased that the variable is being measured in a valid manner. For example, if the output of the agriculture module is operationalized as (1) reported number of bushels of wheat per acre, and as (2) reported number of bushels of corn per acre, the output construct is validated if both measures increase concordantly. If they do not, the definitions are not converging and therefore one or the other or both are not valid.

A second criterion important for evaluating simulations used in extremal experiments is the "precise" correspondence between the hypothesized relations among the variables in the simulation and those in the system being simulated. If the agriculture module hypothesizes that agricultural output will increase when the number of tractors is increased, then once both variables are defined, the correlated increases must be demonstrated to occur. Both construct validity and "hypothesis validity" are critically important to establish prior to doing extremal experiments since such experiments assume that both the variables are being measured "well" and that the functional form relating the variables is known (see Fedorov, 1972, p. 6). However, for the reasons outlined in §1 the simulation reported on here is viewed more as aiding in elucidating more micro-level or global attributes and behaviors. As a result there are several validity issues which must be resolved prior to extensive consideration of construct and hypothesis validity questions.

It was argued in §1 that it was necessary to model the internal structure of the government. Thus (using the language of Zeigler, 1970) the desire is not only to establish an input-output morphism between the production systems and the Saudi government but also to preserve certain internal processing relations intervening between inputs and outputs. Measures must therefore be established for bureaucratic variables as well as for external environment variables. For example, bureaucracies in the Middle East vary in their sophistication, and level of trained personnel. Thus their information processing capabilities also vary.

Moreover since the simulation hopefully will be developed from its present primitive state to a more "sophisticated" form, there is no point in applying very strict operational tests to the relations when fairly crude observations are sufficient to suggest needed restructuring. For example, King Faisal is a dominant force in Saudi Arabia, yet his impact has yet to be included. In addition, the agriculture process model completely ignores the role of labor. That is, yield is independent of the number of farmers. Nonetheless, it seems reasonable to require that the simulations be continually monitored in order to ensure a satisfactory final product. Fitting the evaluational criteria to the purpose of the simulation at various stages in its development is consistent with such monitoring. More specifically, the different modules are in different stages of development. For example, thorough defining of converging measures of variables and statistical comparison of postulated with observed relationships among values on the variables is appropriate for evaluation of portions of the agriculture, human resources and oil production modules. That there is a positive correlation between number of tractors purchased and number of bushels of wheat produced is already directly testable. But for the decision module, and for other aspects of the external environment modules, these procedures would be premature. There are at least two important reasons for this claim. First, for examining the output behavior of the decision module, a sophisticated description of the environment upon which it must act is required. Such a description is not yet available. Second, for evaluation of relationships the exact functional form relating variables must be specified. Currently work is still underway examining various possible forms and it is not yet clear just what the most satisfactory form of these functions should be.

Clearly, however, aspects of the module are amenable to other forms of evaluation even at its early stage of development. Townsend (1972) in comparing psychological information-processing models, suggests that the limits of what responses the models can produce is an important place to start in evaluating the models. This can be done at the simulation level only or at both a theoretical and an empirical level. For example, in the agriculture decision module, the amount of fertilization and number of tractors are constrained so that if one increases the other must also increase or remain stable. Whether such a constraint holds empirically is a question that can be investigated.

A second aspect of the simulation which can be evaluated is the degree to which it includes variables which are clearly relevant to the operations it is carrying out. Especially at an early stage of development such questions are crucial to ask of the simulation. For example, the oil production module takes only two inputs, budget for exploration and production. Perhaps skilled labor is also important for determining final production level.

One valuable source of information about what variables ought be included has proven to be policy planners in the State and Defense Departments. These people are actively involved in monitoring the processes being simulated and, as a result, have formed "mental images" of these processes. Initial interviews were conducted to introduce ourselves and our goals to policy planners and to elicit from them their idea of key variables and the relationships between those variables. The overall intent of the interviews was to identify images in the areas of system identification, controls, and outputs. Interviews were performed in the Department of Defense's International Security Affairs and the State Department's Intelligence Research Groups. Subsequently, interviews have been held in the Defense Department's Policy Analysis and Evaluation Agency.

Initial interviews coupled with a preliminary analysis of relevant academic literature in the areas of oil production, agricultural economics and human resource economics produced initial flow diagrams. These flow diagrams were used to generate responses, in terms of agreement or disagreement with the relationships demarcated, from the interviewees. Several of those interviewed responded with helpful suggestions. Unfortunately most of those interviewed (not surprisingly) found the flow diagrams difficult to work with or were reluctant to comment until they could assess what the relationships led to in terms of specific output. Thus current evaluation efforts in part on letting the policy planners interact with the operating simulations.

The above considerations, then, are central to evaluational monitoring of the Saudi Arabia simulation. The last part of this section of the paper will attempt to take an additional step toward evaluation of what remains the most problematical aspect of the simulation - the decision module. The difficulty in evaluating the module concerns possibilities for defining appropriate measures for the variables contained in the module. Two possibilities which may yield a considerable payoff will be discussed.

A first possibility lies in taking an event data approach to defining variables. As described by Burgess and Lawton (1972) this approach defines categories of communications (the "events") and then treats them quantitatively. For example, common event categories for action include diplomatic protest, give warning, protest, and break diplomatic relations. The event data analysis is potentially advantageous to simulations such as the one described here because it does allow quantification of aggregate behaviors. Existent event data are, unfortunately, probably not directly usable in the Saudi Arabia simulation because, first, no one has collected data on all or even many of the events directly relevant to the simulation. Secondly, it is hypothesized in the simulation that information is processed in a culturally dependent way. This means that the access interface of the module itself must determine the coding strategy for identifying and categorizing events. Finally, much of the event data analyses currently available use categories which are too gross for what is needed in the decision module. As was argued in §1, a minimal unit of analysis appears to be the bureaucracy. Once the level of analysis in events data is established, and the events categorized, it is impossible to regain a finer-grained level of information. In spite of these problems, the events data approach seems a potentially fruitful one to try, in that it does allow the abstracting of behavioral occurrences into a usable quantitative form.

A second possibility for measuring variables in the decision module hinges on the module's observation interface with the external environment. The interface operates on the external environment, e.g., the two constraints and their qualitative measurement discussed above, producing a filtered "picture" for the decision module. This process can be indexed by comparing, for example, New York Times descriptions of events to reported perceptions of those same events by Saudi officials and in Saudi technical reports. Once the events data analysis has allowed categorization of Times descriptions, they can be compared to event data analyses of reported perceptions inside Saudi Arabia.

Before event data descriptions can be usefully employed, the language processing capabilities of the simulation discussed above must be implemented. Once the basic language has been specified, the resultant taxonomy of events will allow event descriptions to be coded into the language of the simulation for comparison. In addition, the outputs from the decision module (sentences in the language) can be coded according to existing event data coding schemes. Thus while current event data collection efforts are not directly relevant, the simulation outputs can be made comparable to existing data collections.

In addition to the general problems of validity, there are three questions that pertain to validity that can be asked of the structure of the decision module for the Saudi Ministry of Agriculture. The first is: Does the production system faithfully reflect the manner in which the Saudi's process information about the environment? In the production system illustrated above, this question has several implications. It is the case that the Saudi's make the sorts of distinctions about the information they received that the model assumes that they do? In the production system, an explicit scale is used to represent knowledge about the environment. Additionally, the production system invokes an explicit model of how the environment will respond to various decision module outputs, e.g., levels of the various budgets. The second question is: Are the descriptions of the environment in the decision module consistent with those that the Saudi's use to describe the environment? For example in the decision module, the two variables upon which the description of the environment are based are the fertilizer and mechanization constraints. The third question is: Are the information capabilities assumed for the decision model consistent with the capabilities of the Saudi's? In other words, do the Saudi's have the capability to determine the fertilizer and mechanization constraints. Given that the Saudi's do not currently have the bureaucratic ability to determine the population, it may not be reasonable to assume that the bureaucracy has the capability to perceive these two constraints.

§ 4 SUMMARY

While the arguments presented in this paper do not really settle any substantive issues, they do suggest a strategy for doing simulation based research on the behavior of nations. First, a number of basic principles which must be satisfied by any structure claiming to be admissible to the class of governments were identified. Problems in implementing these principles in a computer simulation were then discussed. Specifically it was argued that governmental bureaucracies be modeled as production systems (linearly ordered lists of "condition → action statements"). Such an approach requires that the modeler pay close attention to the way information is processed within the bureaucracies. This approach was illustrated by operating production system modeling the control of agriculture in Saudi Arabia. The final section discussed problems in validating the computer simulation and proposed the sorts of analyses necessary to a more thorough evaluation.

ACKNOWLEDGMENT

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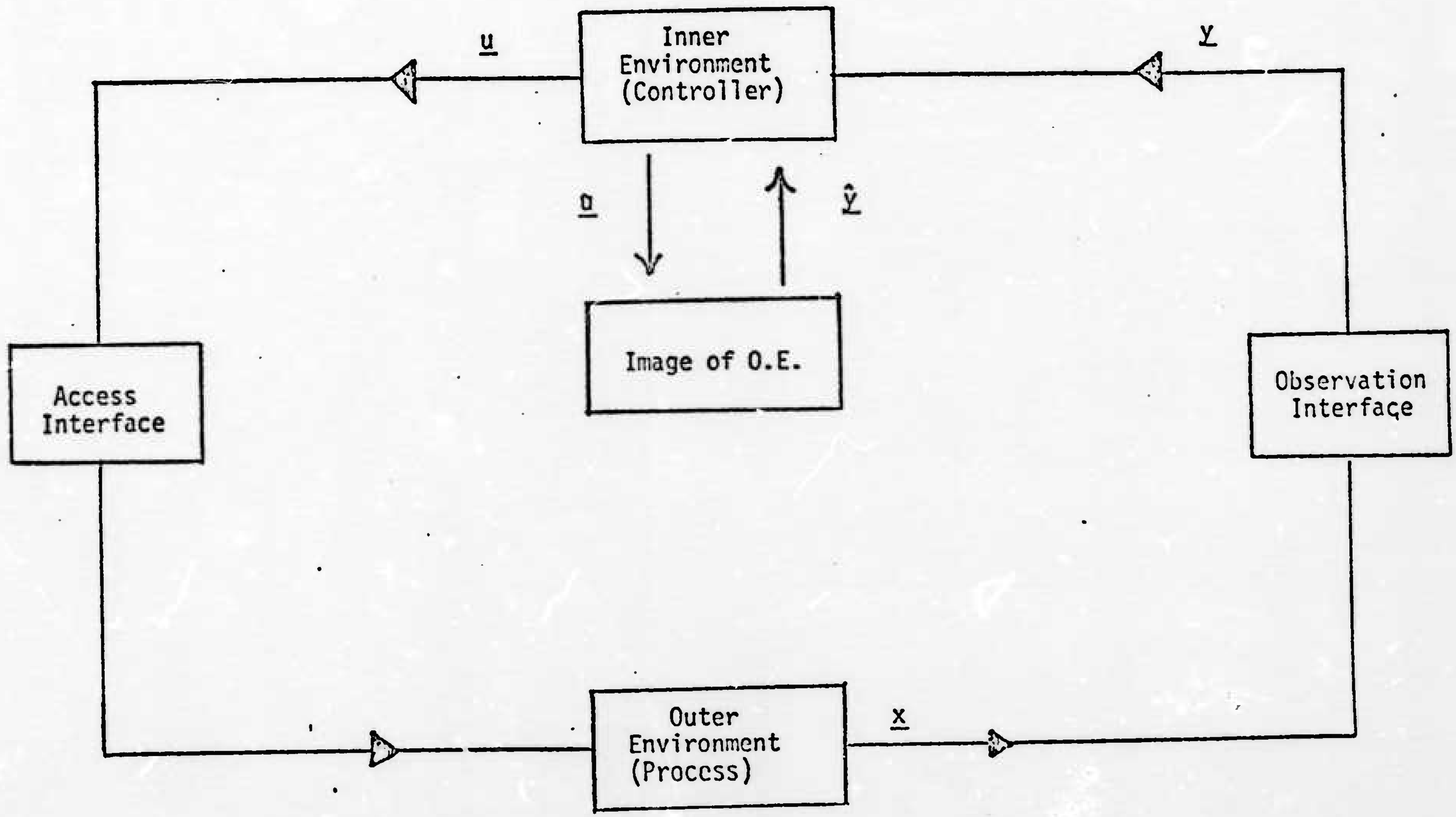
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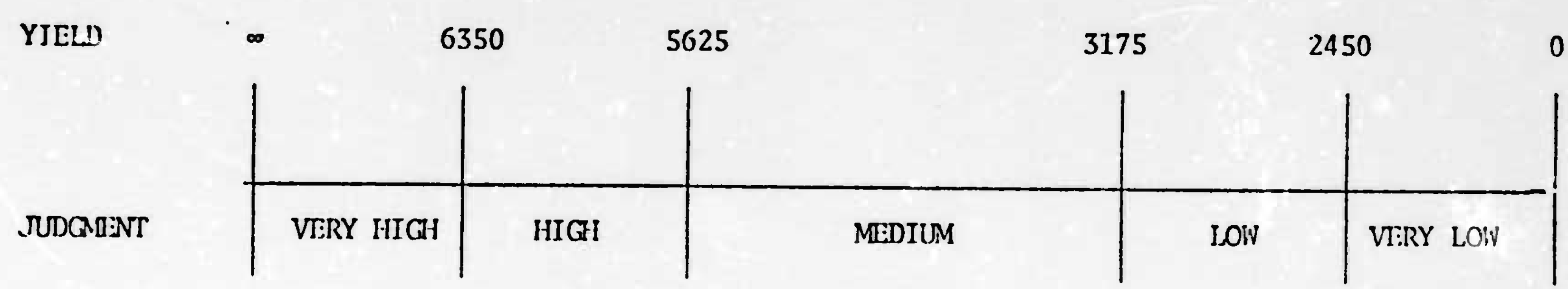
YIELD
∞
6350
5625
3175
2450
0
JUDGMENT
VERY HIGH
HIGH
MEDIUM
LOW
VERY LOW

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P1  Condition (YMECH ABOUT EQUAL TO YFERT, YMECH LOW)
    Actionn   (OLD (**), INCREASE BMECH A LOT, INCREASE BFERT A LOT)

P2  Condition (YMECH ABOUT EQUAL TO YFERT, YMECH VERY LOW)
    Action    (OLD (**), INCREASE BMECH A LOT, INCREASE BFERT A LOT)

P3  Condition (YMECH ABOUT EQUAL TO YFERT, YMECH HIGH)
    Action    (OLD (**) INCREASE BMECH A LITTLE, INCREASE BFERT A LOT)

P4  Condition (YMECH ABOUT EQUAL TO YFERT, YMECH VERY HIGH)
    Action    (OLD (**),INCREASE BMECH A LITTLE, INCREASE BFERT A LITTLE)

P5  Condition (YMECH GREATER YFERT, YFERT VERY LOW)
    Action    (OLD (**), INCREASE BFERT A LOT)

P6  Condition (YMECH GREATER YFERT, YFERT LOW)
    Action    (OLD (**), INCREASE BFERT A LOT)

P7  Condition (YMECH GREATER YFERT, YMECH HIGH)
    Action    (OLD (**), INCREASE BFERT)

P8  Condition (YFERT GREATER YMECH, YMECH LOW)
    Action    (OLD (**), INCREASE BMECH A LOT)

P9  Condition (YFERT GREATER YMECH, YMECH VERY LOW)
    Action    (OLD (**), INCREASE BMECH A LOT)

P10 Condition (YFERT GREATER YMECH, YFERT HIGH, YMECH MEDIUM)
    Action    (OLD (**), INCREASE BMECH)

P11 Condition (YMECH GREATER YFERT, YMECH MEDIUM, YFERT VERY HIGH)
    Action    (OLD (**), INCREASE BMECH A LOT)

P12 Condition (YFERT GREATER YMECH, YMECH MEDIUM)
    Action    (OLD (**), INCREASE BMECH A LOT)

P13 Condition (YMECH ABOUT EQUAL TO YFERT, YMECH MEDIUM)
    Action    (OLD (**), INCREASE BMECH, INCREASE BFERT)
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YMECH = Level of mechanization constraint
BMECH = Budget for mechanization
YFERT = Level of the fertilizer constraint
BFERT = Budget for fertilizer

C.A.C.I.

WASHINGTON, D.C. OFFICES

Critical Review of the Oil, Agriculture, and Human Resources Modules for Saudi Arabia

Suggested Initial Structure for the Decision Module for Saudi Arabia

Initial Assessment of Entire Model by Ex-Flag Officers and Policy Planners

Dr. Warren R. Phillips
Mr. Robert C. Crain

Contract Number: RF280154

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Research Paper No. 38

I. INTRODUCTION

This report is a critical review of, and suggested revisions for, the Saudi Arabian oil, agriculture, and human resources modules of the Project for Theoretical Politics. It also presents a recommendation for the initial structure of the governmental decision module that links the three substantive modules. Finally, it reports on the results of interviews with ex-flag officers and policy planners. In those interviews, the substantive modules were presented together with the proposed decision module so that the overall model could be critically assessed from the planner's point of view.

The review of the substantive modules was conducted in conjunction with area specialists and economists, and two types of criteria were employed in their assessments. The first type was concerned with the appropriateness of a module for its intended purpose. For example, since the substantive modules were all to function as models of processes to be controlled by the decision module, they had to be capable of accepting control inputs. Not only must these modules be dyanamic in that sense, but the control inputs identified in each module had to be governmental policies or actions, or variables that could be unambigously linked to one or the other. The second type of assessment criteria was concerned with a module's completeness and internal logical consistency. In essence, the search was for causal links that were inadequate, erroneous, omitted, or unnecessary. Toward this end, the assistance of area experts and economists was especially helpful.

Area specialists were also consulted during the formulation of an initial version of the decision module's structure. The many factors influencing Saudi decision-making and their complex and subtle interactions combined to make that formulation the most difficult task performed for this effort. The resulting structure should be regarded as a first cut whose continued development is essential.

The remainder of this report relates in detail the tasks mentioned above. Critical assessments of the oil, agriculture, and human resource modules, respectively, are presented in the next three chapters. Chapter V describes the suggested initial structure for the decision module, and Chapter VI presents the responses of ex-flag officers and policy planners to the model as a whole, together with resulting suggestions for further revision. Chapter VII speculates briefly on the implications of these efforts for the project's future research priorities.

II. CRITICAL ASSESSMENT OF THE OIL MODULE

The oil module, as presented in the Appendices to the Project for Theoretical Politics Research Paper #23, was considered reasonably acceptable on the criteria of appropriateness. It was specifically designed to be dynamic, with control inputs identified explicitly for the production subcomponent in Research Paper #15, and for the contractual (revenue-generating) component in Research Paper #23. Criticism elicited during the review process dealt with particular links in the model and each criticism will be discussed in turn belo .

The first problem identified centered on the delay that occurs between a decision to increase production capacity through capital investment and the actual placement on-line of the new facilities. This delay, given in months, is the variable ADBR in the module's production subcomponent, and was set at three months in Research Paper #23. It was suggested that this value was unrealistically small and should be made larger. Just how much larger, however, depends on which of two assumptions is to be made. One possible assumption is that the increase in production capacity should result from the extension of pipelines and other gathering facilities to fields or pools that already contain drilled and capped wells and/or are near present production areas. For this type of increase in production capacity, a delay of six months may be considered reasonable. The second possible assumption is that any increase in capacity should result from drilling in, and then building gathering facilities for, fields or pools with only negligible development work already completed. Bringing such relatively undeveloped areas on-line would require a longer delay--perhaps two years. The former assumption is better for the project's purposes. The initial drilling and capping of wells in new fields or pools for future production is not an uncommon practice, and since daily production per well is so high in most Saudi oilfields, sizeable increases in capacity may be obtained by bringing on-line already initially developed areas or drilling a few new wells in or very near an already developed area. The important restriction to bear in mind is that very large increases in capacity cannot be brought on-line quickly since gathering facilities already in operation would become saturated. Thus capacity-increase decisions fed into the module should be incremental and continued over a period of time to obtain moderate-to-large increases in capacity.

Another problem identified during the review concerns the omission of any requirements for capital investment to replace production capacity (equipment and wells) which becomes worn out or requires maintenance. This problem may be resolved by adjusting the production capacity (PC) variable at the end of each year. Capacity would decrease by a constant proportion equal to the reciprocal of the assumed average lifetime for that capacity, and could increase (back to its previous value) if capital were invested in replacement capacity. Thus the following equation would be invoked by the oil module at the end of each year:

$$PC_t = PC_{t-1} \left(1 - \frac{1}{\mathrm{LIFETIME}}\right) + \frac{\mathrm{IREP}}{\mathrm{COCR}}$$

where PC = production capacity $\left(\frac{\mathrm{bbl}}{\mathrm{da}}\right)$

LIFETIME = length of time at the end of which capacity is worn out (yrs)

IREP = investment for replacement of capacity (\$)

COCR - cost of capacity replacement $\left(\frac{\$ - \mathrm{da}}{\mathrm{bbl}}\right)$

Replacement of existing capacity is thus handled separately from expansion of capacity to permit production increases.

The treatment of additions to proved reserves should also be revised. Presently, such additions are based on monthly production rates, with PRM, the average ratio of net increases in reserves[1] to production levels, having

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[1] Net increases in reserves are equivalent to total new reserves discovered in a given time period minus cumulative production for that period.

been estimated from past performance. A better approach would estimate a fixed gross discovery rate from past performance. The resulting incremental growth in reserves could be overridden by the user if he so desired. The level of proved reserves could be arbitrarily increased by 50 percent for example, in order to simulate large new discoveries. Then incremental growth would resume. The phenomenon of consistently increasing reserves over time is unique to Saudi Arabia.[2] While incremental growth in Saudi reserves is a reasonable assumption for the present and at least short-term future, it should not be assumed over the very long term.

Some additional points made with respect to the module should be covered. First, the oil demand experienced by Middle Eastern producing countries is subject to seasonal fluctuation. This is not presently addressed in the module; on the other hand, most planning decisions by the producing-country governments are made on a fiscal-year basis and thus such fluctuations tend to balance out for decision purposes. Their omission is probably justified. Second, as Saudi Arabia moves toward a complete take-over of ARAMCO, the revenue-producing equations in the module may require additional revision since they explicitly reflect contractual terms. This problem could be overcome by aggregating the contractual terms into the imputation of a single net revenue per barrel figure for the government; but this would perhaps overly simplify the module's representation of the government's decision environment. On the other hand, operation of the production facilities as wholly Saudi-owned may yield a contractual basis which replaces the complex previous arrangements with a single price for oil and, in effect, obviates the problem.

The remaining problems with the oil sector lie not in the oil module itself but in the means of producing control inputs for it. More specifically, they lie in the specification of decision algorithms which produce the control information. These problems will thus be discussed in Chapter V.

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[2] Hitti and Abed (1974: 252). See also Warman (1973) for the difficulty in predicting future discoveries.

III. CRITIQUE OF THE AGRICULTURE MODULE

The agriculture module received more extensive criticism than the oil module. The module was dynamic and the control inputs required were budget and policy matters, so that the criteria of appropriateness were generally satisfied. In another sense, however, an important criterion of appropriateness was not satisfied. The agriculture module was constructed because it was thought that a drive toward agriculture self-sufficiency would be a major part of Saudi developmental policy. Area experts indicated, however, that references to such an effort in, for example, the most recent Saudi development plan are largely cosmetic. The funds allocated for agricultural development are nowhere near sufficient for the intense effort assumed as an underlying rationale for the module. Instead, the Saudis appear largely willing to import food to fill any deficit between domestic supply and demand. Hence the usage of the module within the overall model should be revised.

The traditional sector of the agriculture module can be largely ignored. People in this sector are engaged in subsistence agriculture. Crops grown by them are consumed locally and contribute little or nothing to the supply of food for the country's ubran regions. Individuals engaged in subsistence farming do represent a sizeable source of labor which, with education and training, could be diverted to a growing industrial sector. Rather than free up labor in the traditional sector by modernizing agriculture and greatly increasing individual productivity, however, the Saudis are considering importing surplus agricultural workers from Egypt.[3]

The modern sector of the agriculture module should also be treated differently than was originally envisioned. The Saudis are likely to make an extensive effort to develop a large, modern, irrigated agricultural

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[3] See the summary of key features of the new five-year development plan for Saudi Arabia in Arab Press Service, May 26, 1975, p. 10.

sector only if the cost of importing food for urban areas exceeds some (relatively high) threshold or if insufficient quantities of food are available for purchase. There is, however, an ongoing government experimental farm program and some limited development of irrigation projects.[4] It was suggested, therefore, that the agriculture module's modern subcomponent be regarded as reflecting an experimental operation in which an ongoing effort is made to discover the optimum technology (usage combination of land, water, machinery, and fertilizer) for Saudi conditions. This could be easily accomplished by setting low limits on the amounts budgeted annually for fertilizer, machinery, and additional irrigation development and allowing a subcomponent of the decision module to attempt optimization under these constraints. The technological level achieved by this experimental effort at any time (as measured in terms of yield with specific mechanization and fertilization levels) could be used to produce estimates of how much it would cost at that time to gear up to produce a given quantity of wheat if a major development program were undertaken. If the excessive import cost threshold mentioned earlier were to be exceeded, then agricultural budget expenditures would be increased drastically in an effort to employ technology from the experimental farm on a much wider scale.

The import demand for food would be generated by replacing the present demand equation (C2 in Research Paper #32). Instead of the population index (POPI) and population growth (POPGR) variables representing the population as a whole, they would represent the level and growth rate of the urban population. The world price of wheat variable (WP) would be used to approximate the cost of importing the needed wheat provided that an adjustment for transportation costs is applied.

Given this overall shift in the usage of the agriculture module, several criticisms and suggested revisions of particular aspects of the modernized sector subcomponent should be addressed. The first criticism deals with

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[4] See, for example, Eigeland (1970: 22-29).

the delay involved after a budget allocation has been made for a new irrigation project and before that project is completed and performing at its design level. It was pointed out by economists that a shakedown period of one to two years is normally required after such a project is completed before it functions smoothly and reliably. Thus, the delay variable (IRRDELA) in the module should not be based solely on published estimates of construction time to completion. In addition, irrigation projects which involved dams may require different delay times than projects based upon ground-water wells.

Another suggestion was to establish a range of estimates for coefficients in the module's equations. Since many coefficients have been estimated on the basis of spotty or otherwise inadequate data, or their values simply assumed, estimates of high and low values should be provided in addition to the original value. The module may then be subjected to sensitivity testing the determine those coefficients whose values are most critical and which thus merit more careful estimation if possible.

The adjustment of the government's cost of subsidizing mechanization (for wheatland as a proportion of total irrigated land) in equation P4 should be removed. It is highly unlikely that a Saudi planner, when considering the cost of providing farm equipment for a given area, will be concerned with allocating portions of that cost to the production of different crops. In addition, wheat has been taken as an indicator of the entire agricultural sector, and all fertilizer purchased by the government is assumed to be applied to wheat; thus allocating all machinery cost to wheat is consistent with other assumptions.

The geographic distribution of machinery is another consideration which was not addressed directly in the module. There are essentially two strategies that a Saudi decision-maker could employ when providing farm machinery. The first is to distribute the equipment uniformly over the land to be mechanized. The second is to determine the level of mechanization required to produce high yields and then concentrate the machinery on a portion of the land which could be mechanized in an attempt to reach a target yield figure. The implications of these strategies for total production may be quite different. Economists suggested that the probable tendency of a typical planner would be to concentrate the machinery in smaller areas, and that the possibility that such a policy might constitute suboptimization should be considered.

The effects of geographical distribution are partly embedded in the line representing yield constraint as a function of mechanization level. If there is a "critical mass" effect with machinery so that minimum amounts are necessary for a given land area before much of an impact on yield occurs, the line would have a step-level change at some point instead of being continuous as is presently the case. A straight line would imply that, ceteris paribus, uniform distribution of machinery would be the optimal policy while the step-level increase would imply the opposite unless sufficient machinery was involved to bring the entire area above the threshold.

Roughly analogous remarks could be made about fertilizer distribution except that the shape of a fertilizer yield function is well known and the smooth curve presents a rather straightforward optimization problem to the planner. A family of curves having the same shape should, however, be used to determine the effects of a range of assumptions.

Economists also suggested that it would be desirable to combine the effects of fertilizer, water, and mechanization on yield into a single function since their effects are interactive.[5] It was recognized, however, that this might be extremely difficult and perhaps impossible depending on the amount of information available. At a minimum, a family of curves should be tried for each separate function, where each curve would represent the best estimate of yield response to a particular input given explicit assumptions of the values of the other inputs.

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[5] Each of the present yield curves represents, in effect, a partial derivative of yield with respect to some given input.

A by-product of the discussion of yield curves was the identification of an additional assumption implicit in the curves of Research Report #32. The assumption is that water and fertilizer are always applied at the appropriate times. This may be an appropriate assumption for an experimental farm, but it is by no means trivial.

The equation (C2) used to calculate demand for wheat should be modified to remove the assumption of a constant income elasticity. Economists pointed out that demand may only increase with income up to a point; beyond that point it may remain constant or decrease. The assumption of constant elasticity is appropriate only if it is also assumed that per capita income will not rise above the point at which demand levels off or decreases. An indication of the acceptability of the second assumption might, it was suggested, be gained by examining per capita demand for wheat in other countries at various levels of development. If the second assumption is found to be unwarranted, the income elasticity of demand for wheat should be made a function of private consumption expenditures.

Fault was also found with measures of income and productivity employed in the agriculture module. Economists pointed out that income for the agricultural sector is usually measured on a per family rather than a per person basis (especially where agriculture is largely traditional). Given that the agriculture module's traditional sector will now be ignored, however, there seems little reason to retain a measure of agricultural family income. Similarly, the labor productivity measure should be revised to provide information only on those involved in modernized agriculture.

Finally, it was suggested that purely definitional equations (such as that for labor productivity) be removed from the model per se, as they make it somewhat cluttered. Since such equations define monitor variables used as performance indicators, they may be relegated to the decision module's observation interface.

IV. CRITIQUE OF THE HUMAN RESOURCES MODULE

On first reading, the human resources module appears to be the best of the three. Unfortunately, when the criteria of appropriateness are applied against the module, it is seen to have serious faults. The main problem is that the module is not dynamic. Transition constants that determine implicitly the population growth rate and explicitly the flow from category to category within the module are static. There exists, for example, no way for educational expenditures to influence the number of students or the dropout rate. This state of affairs was acknowledged in part IV of Research Paper #31, as was the solution: a set of algorithms relating transition constants to government expenditures or other policies. No work has been done along these lines, however, and thus a most undesirable situation exists for the decision module. Perhaps the most critical sector in terms of its impact on potential development is not susceptible to control. Essentially there are only two remedies available: provide the algorithms or redo the module.

In addition to the lack of control input to the human resources module, there exist several problems of a more substantive nature which were pointed out by area experts. To begin with, the module does not distinguish between Saudi Arabia's indigenous labor force and the relatively large amount of skilled foreign labor employed there. Not only is skilled foreign labor presently used in large quantities, but the current Saudi development plan suggests that even more will be imported.[6]

Another problem with the module is that it does not distinguish between students enrolled in religious schools and universities and those enrolled in modern conventional ones. The graduates of the different types of schools differ in their capabilities to become effective managers, technicians,

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[6] See Arab Press Service, May 26, 1975, p.10.

and bureaucrats quickly. In addition, estimates of population (and, as a result, those for manpower) are probably too high. The population estimate of 8,200,000 for 1972 in the module, for example, should be adjusted downward in light of more recent estimates of 1972 Saudi population of 7,200,000 from one source[7] and 4.1 million from another.[8] For planning purposes it would seem more appropriate to employ the lower estimate because of its implications as a bottleneck, but a range of estimates should be tested for their implications.

Estimated percentages of the work force falling into various categories are also somewhat erroneous. In particular, the percentage (74.0) for self-employed agricultural workers should be lowered (to about 45 percent), and that for petroleum wage earners (1.0) raised (to about 2.5). Taken as a group, the self-employed non-agricultural, non-industrial wage earner, and non-petroleum industrial wage earner categories should be increased from 10 percent to about 30 percent. Area experts emphasized that, in general, there exists a relatively wide range of estimates in various published sources of both the Saudi population and its breakdown by manpower and other human resource categories. Thus it becomes important to look for convergence when selecting estimates from the literature or to employ a range of estimates if no convergence exists.

The preceding criticisms have focused largely on the data used in estimating model parameters. The module also assumes the values of some parameters in order to estimate others. Area experts were specifically requested to assess the values assumed in light of their knowledge. The assumption of .75 for X_{22},[9] which implies that 25 percent of the pupils in primary grades either move into the intermediate grades or drop out, was considered reasonable. Similarly, the assumed value of .5 for X_{33} (the proportion of intermediate school pupils returning each year) was

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7 Hitti and Abed (1974:247)

8 Knauerhase (1974:127)

9 The subscripts of X represent its position in the transition matrix shown on p. 19 of Research Paper #31.

not criticized. The value of .075 estimated for X_{32}, however, was regarded as probably a bit small; more than 7.5 percent of the primary-level pupils probably go on to the intermediate level. Since X_{32} was estimated, X_{33} would have to be reduced slightly in order to raise X_{32} somewhat. Alternatively, one might assume that the error results from inaccuracies in the data and retain the present value of X_{32}. Given the importance of substantively reasonable assumptions and the difficulty of obtaining data on the Saudi educational system, the better choice for the present situation would probably be reestimating X_{32}.

Other transition constants were criticized. Perhaps the best procedure of reporting the criticism is to do so by manpower category into which people are flowing. In terms of the transition matrix in Research Paper #31, this means that the constants will be reported on a row at a time. In row 6, X_{613} is assumed to be zero, and thus no self-employed, non-agricultural workers (for example, shopkeepers and owners of taxis or auto repair shops) attend school. This is incorrect. Most of those attending adult basic education classes are high-achieving, self-motivated individuals, and are likely to come from this self-employed category. Similarly, an examination of the constants in row 7 suggests that each year 15 percent of those enrolled in technical/adult education enter a university. University students come almost entirely from secondary schools, and therefore X_{76} should be near zero.

The source of petroleum wage-earners is indicated in row 8 to be the unstructured pool. In reality, nearly all of those hired by the oil industry have at least a primary education, and at least a few are university graduates.[10] Thus X_{82}, X_{84}, and X_{87} should all be greater than zero. Non-petroleum (industrial) wage earners are shown in row 9 to come entirely from the unstructured pool and intermediate education. Some industrial workers, however, come from technical schools, and one would assume that at least some industrial managers are college graduates. Thus X_{96} and X_{97} should be greater than zero. Some uncertainty exists

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[10] Letter from W.P. O'Grady of ARAMCO.

with respect to X_{102}. It has been suggested (Knauerhase, 1974:128) that some Saudi government jobs are filled by dropouts from primary school. Since one would expect only a limited number of jobs for young boys, this would imply that a reasonable number of students in the primary grades start at a late age and then quit as soon as they are able to qualify for government jobs. If such students are included in the primary (elementary) education category, then X_{102} should be greater than zero. If, on the other hand, such students are included in the adult/technical education category, the assumption that X_{102} is equal to zero is quite reasonable. Additional knowledge of the structure of the Saudi educational system is necessary to resolve this problem. In addition, the graduates of teacher training schools are employed primarily by the government. Instead, such individuals are shown entering several different categories. Thus X_{105} (the proportion of teacher training pupils entering government service each year) is too low and some other transition constants in column 5 are too high.

Area experts pointed out that the Saudi army draws most of its officers from secondary school graduates and most of its enlisted men from illiterates, with almost none of its officers having university degrees. Accordingly, the figures of .067 for X_{117} (univeristy students), 1.0 for X_{116} (technical/adult school students), and .133 for X_{115} (teacher trainees) should be zero or near zero.

The non-industrial wage earner category has a value of .133 for X_{125} (the transition constant from the teacher training category). As pointed out earlier, teachers work primarily for the government, and the assumption that 27 percent of those leaving each year (or 13.3 percent of the total number enrolled) enter this category is probably too high.

The final substantive criticism made by the area experts is that the module permits no flow from the agricultural self-employed category to non-agricultural labor categories such as oil, military, and non-industrial wage earners. A major thrust of the Saudi development effort is to transfer manpower out of subsistence agriculture and into more productive employment by bringing in foreign agricultural laborers if necessary. The assumption that X_{114} through X_{1314} are all zero is thus not justified.

V. SUGGESTED INITIAL STRUCTURE FOR THE DECISION MODULE

Introduction

Development of a plausible initial structure for the Saudi decision module was a difficult task. The Saudi government has a very small bureaucracy relative to its income so that the decision-making process is highly personalist. Very little exists in the way of a published literature to give insight on the process, and data that would permit us to infer something about the process are either nonexistent or often not completely reliable. Moreover, recent large increases in Saudi Arabia's oil revenue, together with the country's emergence as a leader among Arab nations and the increased dependence of industrialized nations on petroleum from the Middle East, have introduced a large element of uncertainty into whatever inferences we might be able to draw from past periods.

Thus the structure presented in this section should be regarded as only a first cut. It will, however, provide a focus for the further analysis of Saudi decision-making and development of a more sophisticated model. Moreover, such a specification was needed in order to link the three substantive modules into a single entity for presentation to policy planners. In the discussion that follows, the suggested initial decision structure will be explicated and needs for further development identified.

Preliminary Considerations

Before attempting to specify the structure of the decision module, it was necessary to decide what kinds of policy outputs are most important in Saudi Arabia. In the developed countries, many kinds of governmental policies may be considered important to the conduct of domestic and foreign affairs. For example, tax policies, regulatory and tariff policies, environmental policies, defense spending, and so on may all have a considerable influence on large parts of a nation's population and economic affairs. In Saudi Arabia, however, the situation is much simpler. Although the government is involved to some extent with all the examples just mentioned, its primary policy focus is the use of oil revenues to develop a diversified economy. It is not extensively involved with relatively subtle tinkering with a large and economical powerful private sector (excluding oil) because none at present exists.

Thus the focus of the decision module became budgetary allocations and how (and why) they are produced. This in turn influenced the module's assumed time frame. Each iteration of the module is equivalent to one Saudi fiscal year. These fiscal years are based on the Moslem calendar, however, and the correspondence between them and Gregorian calendar years is shown below:

Moslem Fiscal Year	Gregorian Calendar Date at End of Moslem Fiscal Year[a]
1382/83	November 16, 1963
1383/84	November 4, 1964
1384/85	October 24, 1965
1384/86	October 14, 1966
1386/87	October 3, 1967
1387/88	September 22, 1968
1388/89	September 11, 1969
1389/90	September 1, 1970
1390/91	August 21, 1971
1391/92	August 9, 1972
1392/93	July 30, 1973
1393/94	July 20, 1974

Since the Gregorian date on which the Saudi fiscal year begins changes each (Gregorian) year, the decision module must keep track of this. For the human resources module, the changing start date is unimportant. The

[a] Source: Hitti and Abed (1974: 279).

slightly longer Gregorian years have been used in the estimation of transition constants, but this is assumed to be negligible for present purposes. For the agriculture model, the changing start date is also probably irrelevant at present because relatively little central agricultural planning and budgeting have been done in the past or are being done presently. The oil module operates on a monthly basis and exogenous disturbances that affect it (for example, a reduction in demand) may be introduced during any month. The effects of such a disturbance may well be quite different depending on whether it occurs at the beginning, the middle, or toward the end of a fiscal year. Thus, if the decision module is assumed to iterate once per Saudi fiscal year, the month in which the oil module starts must correspond--at least roughly--with the start of the fiscal year involved. A simple way of approximating the desired correspondence would be to change the oil module's start month to the next earlier month every fourth year.

Given that the decision module was to be concerned with budget decisions and was to operate on the basis of the Saudi fiscal year, we could progress on the module's basic structure. The result is shown in the flowchart in Figure 1. Each step in the flow will be discussed briefly below, along with its underlying rationale.

Module Description

In the discussion that follows it is assumed that a program exists that schedules the execution of the actual decision and substantive module programs, and communicates with the user of the simulation when necessary.

As indicated in the flowchart, the user is first asked for the date at which the simulation is assumed to begin. Because initial values must be specified for a host of variables for whatever start date is assumed, it is suggested that a reasonable default start date (or set of dates) be chosen and initial values for all appropriate variables for that date (or dates) be read into the program from a permanent file.

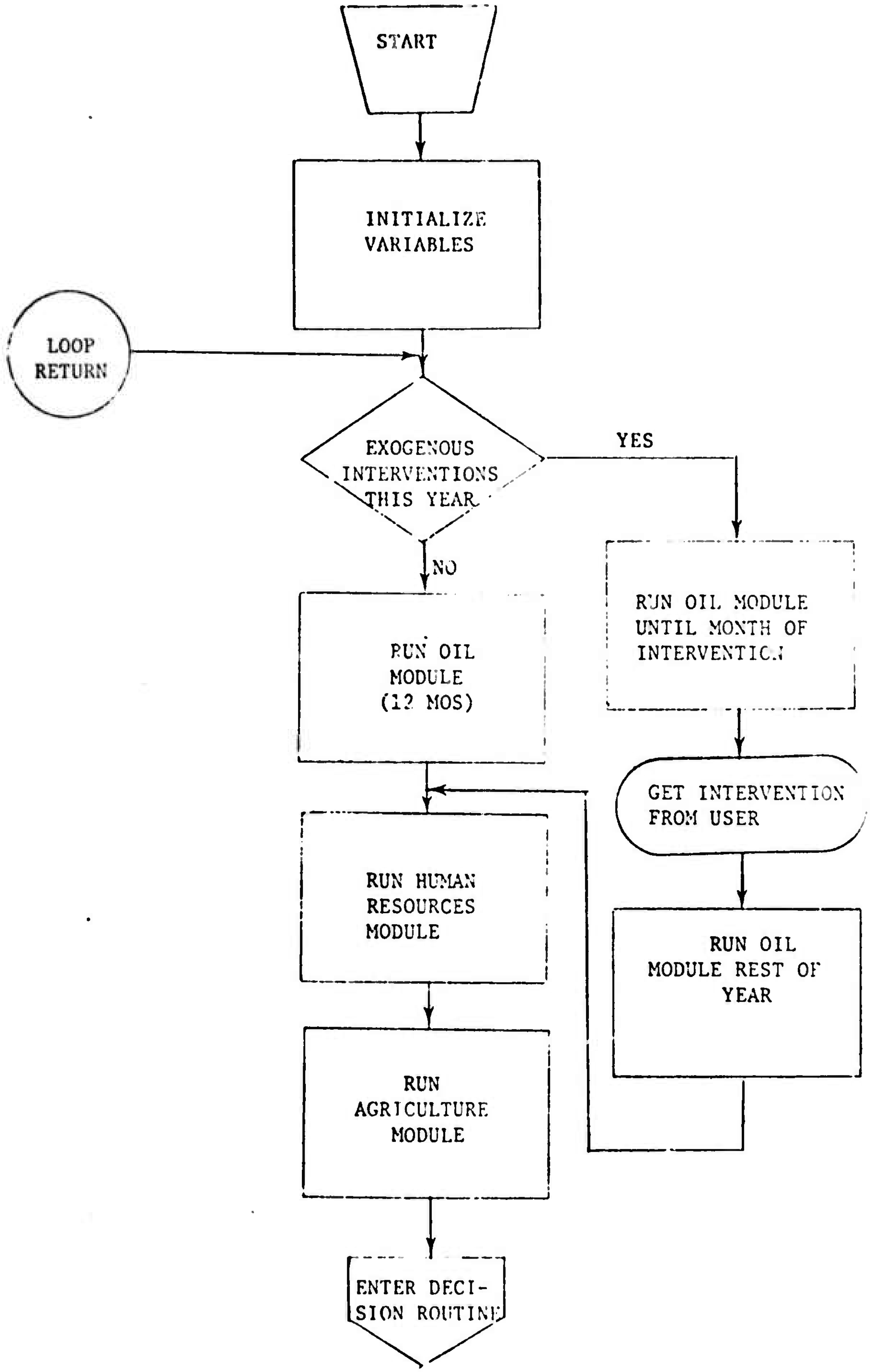
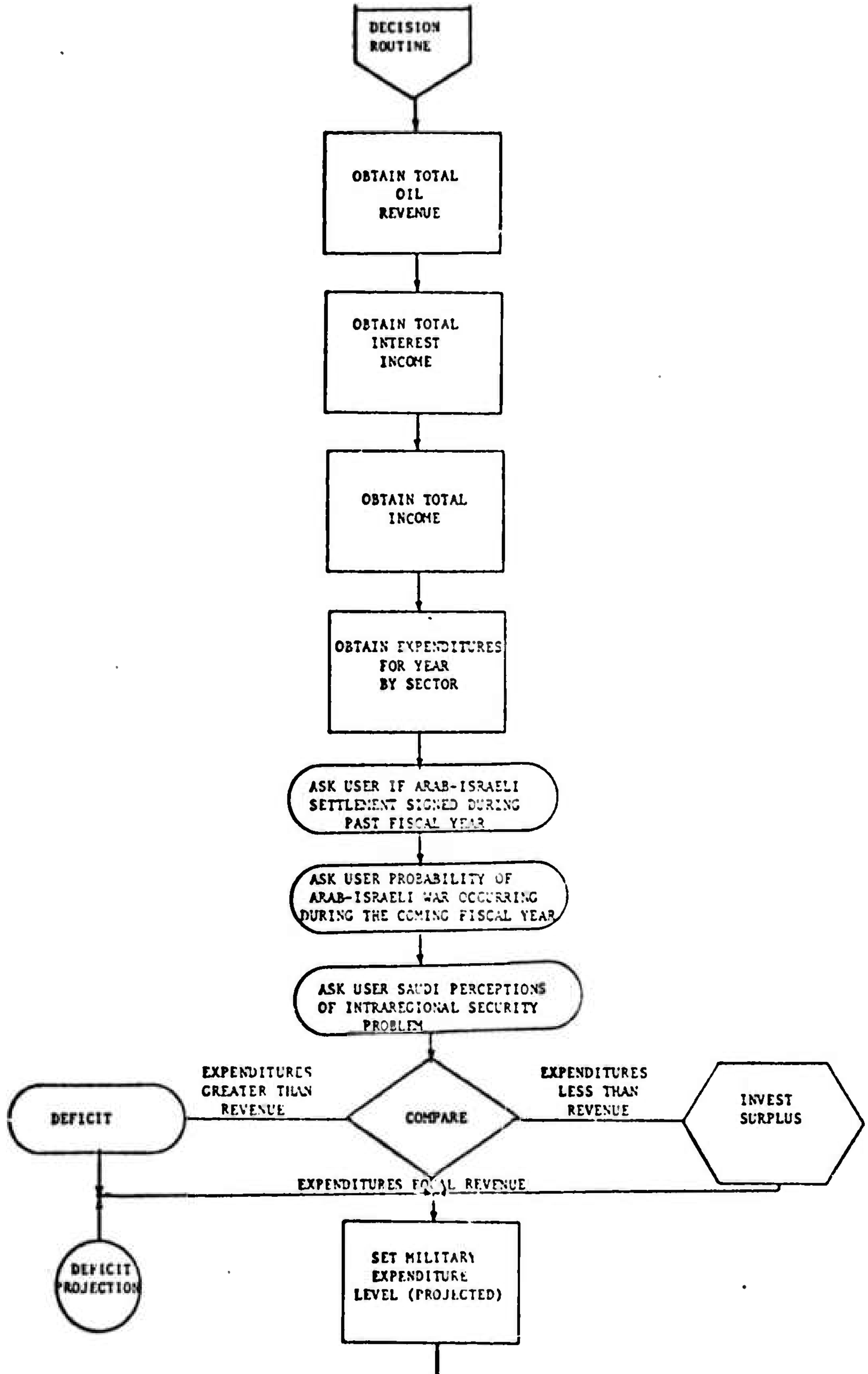
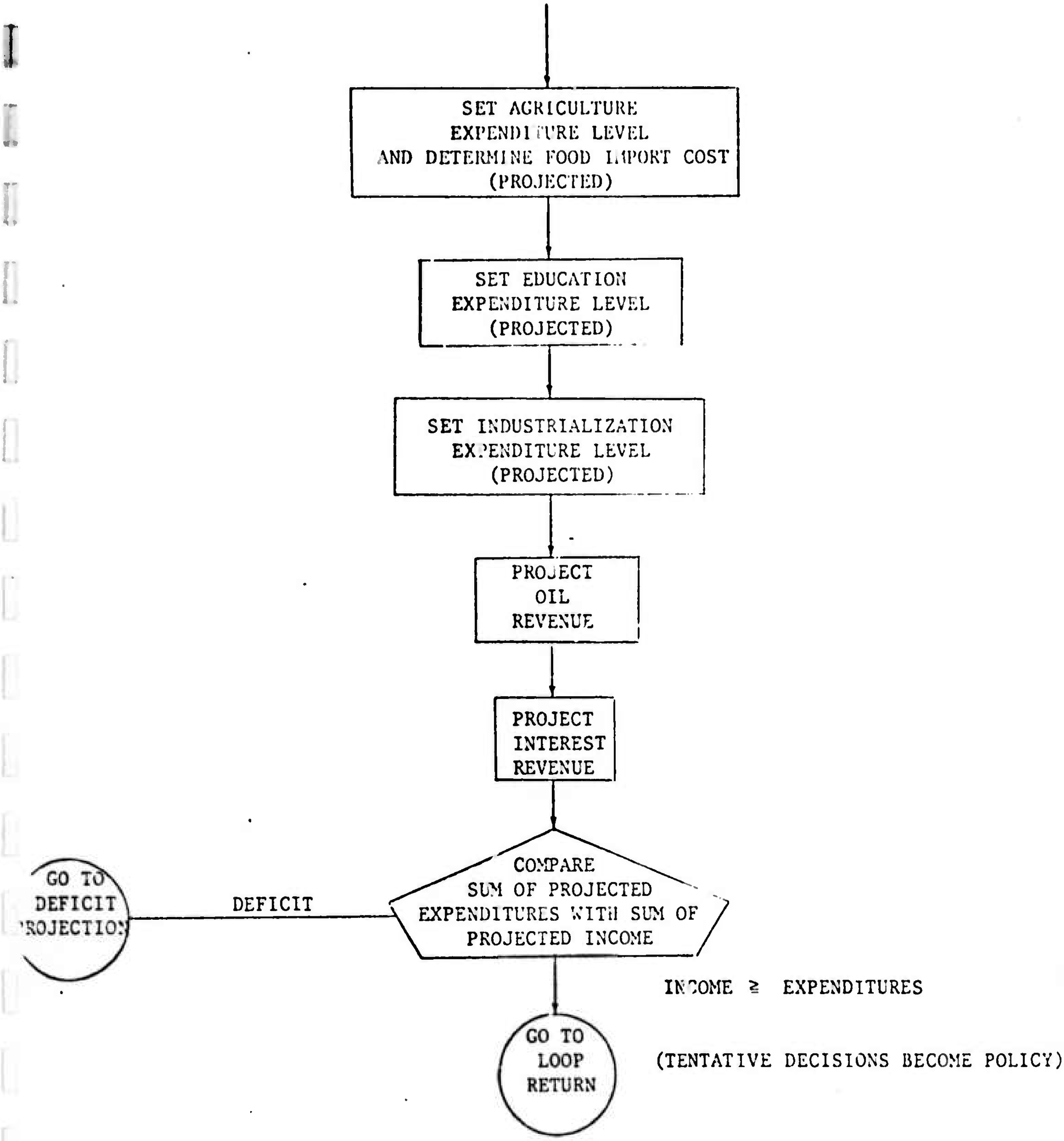


Figure 1. Flowchart of Decision Module


DECISION ROUTINE
OBTAIN TOTAL OIL REVENUE
OBTAIN TOTAL INTEREST INCOME
OBTAIN TOTAL INCOME
OBTAIN EXPENDITURES FOR YEAR BY SECTOR
ASK USER IF ARAB-ISRAELI SETTLEMENT SIGNED DURING PAST FISCAL YEAR
ASK USER PROBABILITY OF ARAB-ISRAELI WAR OCCURRING DURING THE COMING FISCAL YEAR
ASK USER SAUDI PERCEPTIONS OF INTRAREGIONAL SECURITY PROBLEM
EXPENDITURES GREATER THAN REVENUE
DEFICIT
COMPARE
EXPENDITURES LESS THAN REVENUE
INVEST SURPLUS
EXPENDITURES
REVENUE
DEFICIT PROJECTION
SET MILITARY EXPENDITURE LEVEL (PROJECTED)



END DECISION ROUTINE

The date suggested as the default value is July 1974. This corresponds to the beginning of a Saudi fiscal year, and is also conveniently after oil production was no longer being influenced by the embargo of late 1973 and early 1974. In the remainder of this chapter it is assumed that the suggested date has been used. The user would be allowed to choose another start date, but only if he was prepared to provide the initial data required. Similarly, the project staff could employ other (earlier) start dates in order to test the simulation's validity.

After the user has chosen the simulation's start date, he is asked when (month and year) he will wish to introduce a disturbance (make a change in the value of an exogenous variable). This date is stored, and a determination is made of whether the date falls within the coming Saudi fiscal year. If so, the oil module is run until the month in which the intervention is scheduled has been reached. The user is then prompted to provide the intervention. After his reply, the oil module resumes execution (for that month and until the end of the fiscal year).[11] If the date for the first module intervention does not fall within the coming fiscal year, then the oil module executes for 12 months without interruption.

After the oil module has executed for 12 months (with or without an interruption) the human resources and agriculture modules are each executed in turn. The end of the fiscal year has thus been reached.

The supervisor program then prompts the user for one piece of factual information and two pieces of information about Saudi perceptions which will be used by the decision module. The user is asked whether an Arab-Israeli settlement has been signed (yes or no). He is next asked about the Saudi perception of the probability (high, moderate, negligible) of an Arab-Israeli war breaking out during the next (fiscal) year. Finally, he is asked to provide information on the Saudi perception of the severity (extremely severe, severe, moderate, negligible) or intraregional (other than Arab-Israeli) security problems. Then the decision module begins execution.

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[11] It has been assumed, for the sake of simplicity, that only one intervention per year is desired. More than one may easily be permitted.

It will evaluate the various sectors' performance for the year just ended and decide on spending levels for the fiscal year to come.

In reality the Saudi planning and decision process is an ongoing one; to have the decision module function only at the end of a fiscal year is an obvious oversimplification. Yet to attempt to have the module produce control information for the oil module on a monthly basis or work incrementally on the coming year's budget is probably overly ambitious until more is known about Saudi decision-making. Thus, for present purposes, "time will stop" while the decision module evaluates and plans.

The evaluation of the fiscal year just ended is a relatively primitive one. First, information on revenue from oil production for the year is obtained and added to the interest on short- and long-term investments to obtain total revenue.[12] Then government expenditures for all sectors are summed. Total expenditures are compared with total revenue and the result is either a revenue surplus, a revenue deficit, or an approximate balance between revenue and expenditures. If a revenue surplus has occurred, the government must decide what to do with its excess revenue. The choice is between two alternatives: long-term investments (real property or equities) or short-term investments and bank deposits. It is assumed that Saudi Arabia will not put much into the long-term investment category unless an Arab-Israeli settlement has occurred. Given such a settlement, the proportion of surplus funds invested in this category would probably be small initially and rise over time to some ceiling proportion that represented the Saudi's desired liquidity goal. (See Figure 2). The remaining funds would be placed into the short-term category. If a settlement has not occurred, it is assumed that all surplus funds would go into the short-term category. If a settlement has occurred, but for some reason appears likely to break down in the coming year, the surplus would all be placed into the short-term category. An approximate

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[12] Non-oil domestic revenue is very small and is being ignored for present purposes.

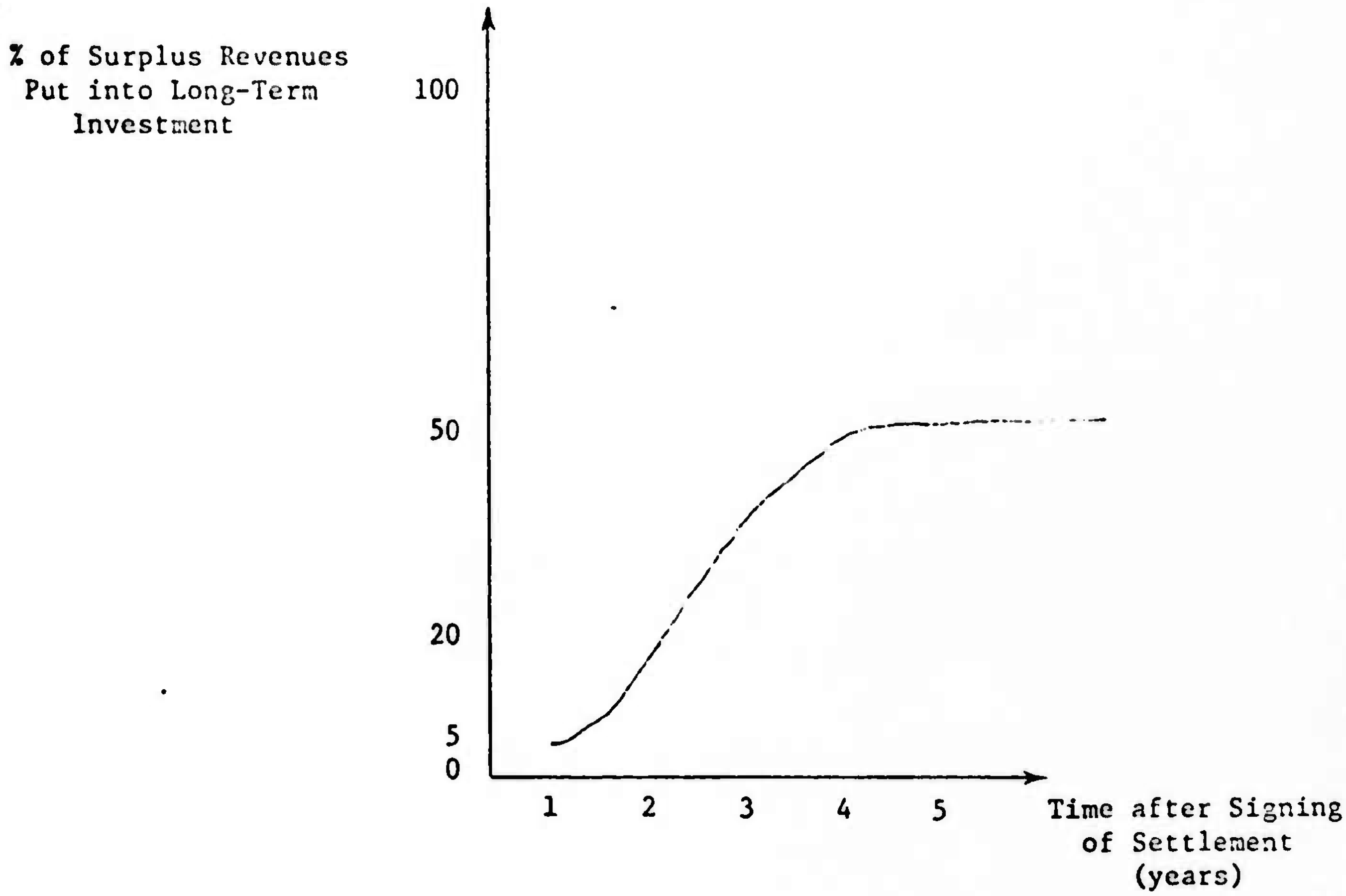

Figure 2. Level of Long-Term Investment after Arab-Israeli Settlement

balance between revenue and expenditures would result in the small surplus being invested (or banked) on a short-term basis or the small deficit being covered by a withdrawal from short-term money of the amount necessary to produce a balance. The case of other than a very small deficit is difficult to deal with and is discussed in a separate section later in this chapter. For present purposes it is assumed that if a moderate or large deficit occurs, a branch is made to a deficit subroutine the structure of which is as yet unspecified and control then returns to the beginning of the routine where projections are made of expenditures for the coming fiscal year.

Tentative expenditures for the coming fiscal year are next established by category. The first expenditure level to be set is that for military expenditures. This is assumed to be made up primarily of money spent for imports of military equipment. The algorithm used for setting a trial expenditure level is as follows:

$$M_t = M_{t-1} * (\alpha_1 + \alpha_2 + \alpha_3)$$

where

M = level of military expenditures and α_1, + α_2. + α_3, are coefficients whose values are set according to the following scheme:

$$\alpha_1 = \begin{cases} +.10 & \text{if high revenue surplus previous year} \\ +.05 & \text{if low revenue surplus previous year} \\ .00 & \text{if revenue approximately equals expenditures} \\ & \text{previous year} \\ -.05 & \text{if low revenue deficit previous year} \\ -.10 & \text{if high revenue deficit previous year} \end{cases}$$

$$\alpha_2 = \begin{cases} +.20 & \text{if extremely severe intraregional[13]} \\ & \text{security problems} \\ +.10 & \text{if severe intraregional security problems} \\ +.05 & \text{if moderate intraregional security problems} \\ +.00 & \text{if negligible intraregional security problems} \end{cases}$$

$$\alpha_3 = \begin{cases} +.10 & \text{if high probability of Arab-Israeli conflict} \\ & \text{in next year} \\ +.05 & \text{if moderate probability of Arab-Israeli conflict} \\ & \text{in next year} \end{cases}$$

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[13] Excluding Arab-Israeli Conflict

+.00 if negligible probability of Arab-Israeli conflict in next year.

The second expenditure level to be set is that for education. The algorithm by which this is done is as yet undetermined. A brief summary of the effort made and problems encountered in the attempt to specify such an algorithm may be found in a separate section later in this chapter.

The expenditure for agriculture is set next. This is equal to the amount required to import food (as measured by wheat) for the urban areas[14] plus a small amount (assumed to increase incrementally) for water, fertilizer and machinery to be used in the government's experimental farm program, unless the threshold of excessive import cost has been passed (probably for more than a single year). In the latter case the amounts spent to modernize and develop domestic agriculture would increase drastically. Area experts suggested that the threshold amount is probably very large (perhaps 10-20 percent of the country's revenue), and that it is unlikely to be reached.[15]

The final expenditure to be determined is that for industrial development. It is unclear just what the algorithm involved should be. Information on the new Saudi development plan[16] indicates that approximately $13 billion is to be invested over a 5-year period in building heavy industry, but area specialists suggest that it is unlikely that all of this sum will actually be spent. Since little industry (other than oil) presently exists in Saudi Arabia, it is also difficult to infer what the Saudis might use as performance indicators to assess and adjust an ongoing attempt to build an industrial sector. What is clear is that industrialization is a high priority

[14] The food demand for urban areas would be reduced by the amount of food produced by the modernized agricultural component. This amount will be small unless the threshold has been passed long enough to produce vastly increased domestic agricultural expenditures and for those expenditures to produce results.

[15] In addition, alternatives other than domestic investment exist. For example, it has been suggested that an investment in the Sudan, a country with great agricultural potential but with limited capital, might yield a much greater rate of return than development of domestic agriculture.

[16] Arab Press Service, May 26, 1975, p.10

for the Saudis, that large developmental expenditures will be made in pursuit of that goal, and that thus such expenditures should be taken into account in the decision module.

The projected expenditures in the categories mentioned above are summed and the total is compared with projected revenue for the coming year Revenue projections are made on the following basis. First, interest on investments is computed at user-provided assumed rates of return. To this is added projected oil revenue, which is estimated on the basis of a simple extrapolation from last year's revenues after a check is made of the acceptability of the present production rate. If the present rate is unacceptable, an adjustment is made. The scheme for evaluating production rate and making adjustments is described in a later section of this chapter. If the rate is acceptable, then the extrapolated revenue is added to the projected interest income and the total projected revenue compared with the total projected expenditures. The revenue and expenditure projections are considered satisfactory if an approximate balance or a revenue the supervisor program, which then runs the oil, agriculture and human resources modules for the next year, stopping during the year if an intervention is desired by the user. If a deficit is forecast, then the decision module returns to the point at which military expenditures are projected and cycles through again as if a deficit had occurred during the fiscal year just ended. Presumably, after at most a few iterations, either an approximate balance between projected revenue and expenditures or a projected revenue surplus will be reached and control will be transferred to the supervisor program.[17]

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[17] This is not a trivial matter. If a very large deficit were forecast it would probably be unrealistic to assume that it would be overcome by many successive incremental budget cuts. In such circumstances Saudi decision-makers would probably make bold cuts in one category or another depending on their priorities. As mentioned earlier, inferring what these actions might be is difficult. See the section on deficits in this chapter.

Consequences of Revenue Deficits

As indicated earlier, attempting to specify even very simple Saudi decision rules for coping with a deficit is extremely difficult. At the heart of the difficulty is the need to specify where spending cuts would be made if necessary. It was suggested by area specialists that how the Saudis would respond to a deficit depends on whether they perceive it is a temporary phenomenon or as a long-term trend. Their extraordinary large reserves would permit them to deal relatively easily with any small deficit, and to cope with a large deficit on a one-time basis without insurmountable problems. But even small deficits would probably be unacceptable over time; large ones certanly would.

As described in this chapter, the initial structure of the decision module assumes that the response to a small deficit would be at least a cut in the next year's projected military spending. Presumably, projected spending in certain other sectors would be adjusted downward, and this should be taken into account in specifying budgetary decision algorithms for those sectors. The problem is to identify the sectors to be cut. One means of attacking this problem would be to examine Saudi budgets from 1958 to 1974. During the first decade or so of this period the Saudis had considerably less oil revenue and were engaged in a program to repay sizeable government debts from deficits incurred before Faisal's influence was felt. Then, in more recent years, oil revenue increased steadily. An examination of changes in amounts budgeted in the various sectors as revenue increased, and earlier when debt repayment constrained spending, could shed some light on the ordering of Saudi goals.

Problems Involved with Specification of an Algorithm for Determining Educational Spending

The initial approach to specifying an algorithm for setting expenditure level in the educational sector was to use the human resources module to provide information on the total number of students at all educational levels and then multiply this number by an assumed figure for cost per student. The cost per pupil was assumed to rise incrementally over time until it reached a ceiling value. An estimate of the ceiling value was to be made by examining Kuwait expenditures per pupil. Kuwait would serve as an example of a "mature" oil-rich country in which social welfare expenditures had stabilized at a plateau. In the Saudi budget for the fiscal year beginning July 1974, however, the education allocation was raised 68 percent over that of the previous year, doubtless in part because of the large increase in government oil revenues following the late 1973 price rises. That 68 percent increase, however, put the Saudi per pupil rate at about twice that of Kuwait. Thus the motion of Kuwait as a "mature model" for education seemed to be of rather limited utility. Moreover, no satisfactory explanation for the 68 percent increase could be found, and Saudi expenditures had already been at a very high level. The conclusion drawn was that educational expenditures and their justification would require intensive investigation before an algorithm could be formulated with any confidence

Saudi Evaluation of Their Oil Production Rate

In the decision module, the Saudis are assumed to determine whether the past year's production rate (in barrels per day) is appropriate for use during the coming fiscal year. Its suitability is influenced by several factors. First, the Saudis can sell no more oil than is demanded by their customers; this exogenous variable is thus assumed to act as an upper bound for acceptable production values. Second, in times when demand is less than capacity for OPEC nations taken as a group, each member's production level is set approximately under an informal allocation scheme. Area specialists pointed out that the scheme is quite effective in spite of its informal nature, and thus Saudi Arabia should not be considered to have wide flexibility in setting its production rate subject only to demand constraints.[18] Finally, the production rate is subject to

[18] For example, sizeable Saudi production cuts below their allocation level in a period of unchanging demand would provide pressure for either increased production by other OPEC members (strongly opposed by some members) or increased price (opposed by Saudi Arabia).

constraints concerning reservoir damage and reserve life. Extremely high production rates over short periods of time would violate the former, and at some point even moderate rates would violate the second.

Attempts were made to include these factors in the design for the decision module. It was assumed that the user will provide information on demand. This information would be embodied in a variable which could express demand either directly in barrels per day or in the form of an index relative to demand at the start time chosen.[19] In either case, however, such demand information is further assumed to be adjusted by the user for the effects of OPEC production allocation schemes. Thus this variable forms an upper constraint on production level. If production is at this level and the user intervenes during a fiscal year and lowers this value, then the production rate is lowered immediately to the new value for the balance of the year. Similarly, a rise in demand is responded to immediately if it does not require production in excess of current capacity.

Since downward adjustment of production in response to decreases in demand is automatic, the first check made by the decision module during evaluation of production rates is to make certain that reservoirs are not being damaged or reserves depleted too soon. It has been assumed that these two criteria interact with a third, namely, whether the country's absorptive capacity is surpassed at present levels of oil revenue. The value of this variable may be either given by the analyst (as is presently assumed to be the case) or built into the module. Tables 1 and 2 show how yes/no values for variables representing each of the three criteria are assumed to combine to produce Saudi decisions on production level. Reservoir damage is assumed to occur if the productive level is high enough to deplete reserves in 10 years. It is also assumed that Saudis would undertake strong conservation measures if the ratio of proved reserves to current production is less than 15 years.

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[19] An actual value for production rate would still be required for the start date.

TABLE 1

VARIABLES	SITUATIONS							
	1	2	3	4	5	6	7	8
Absorptive Capacity Surpassed	Y	Y	Y	N	N	N	N	Y
Reservoir Damage Occurring	Y	Y	N	N	Y	Y	N	N
Reserve Life Running Out	Y	N	N	N	N	Y	Y	Y

Y = Yes

N = No

TABLE 2

SITUATION	RESPONSES
1.	Cut production so that reserves/production = 15. The resulting production value will decline each year.
2.	Cut production to just below reservoir damage point.
3.	Maintain production at present level.
4.	Maintain production at present level.
5.	Cut production to just below reservoir damage point.
6.	Cut production so that reserves/production = 15. The resulting production value will decline each year.
7.	Cut production so that reserves/production = 15. The resulting production value will decline each year.
8.	Cut production so that reserves/production = 15. The resulting production value will decline each year.

This figure has been used as the criterion for whether reserve life is running out.[20]

After the module has ensured that the production level satisfies the "normal situation" constraints just mentioned, it checks whether an Arab-Israeli war is occurring. If so, it ascertains whether its customers are supporting Israel.[21] An embargo (expressed as a cut in production) is imposed on Saudi customers if they support Israel.

Given the production level established at this point, the decision module goes on to project revenue for the coming fiscal year on the basis of that level and the price of oil. Area specialists indicated that an OPEC country has only a very limited ability to alter the price of its oil around the price agreed upon at OPEC meetings. Such marginal price adjustments have been ignored in the present model structure. The price of oil is assumed to be an "OPEC" price,[22] and this price is to be supplied exogenously by the user.[23] Once the revenue for the coming fiscal year has been projected, the module goes on to project interest income and then compare total projected revenue with total projected expenditures, as described earlier in this chapter.

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[20] Reservoir damage can occur as the result of production at very high levels for even a relatively short period of time. Since the consequences of reservoir damange (a decline in the amount of oil than can ultimately be extracted from a reservoir) are so severe, it is assumed that production at such high rates would not be considered by the Saudis under most conditions. Moreover, if they did produce at such rates they would do so for only a short period of time (one year assumed at present). Thus if the module finds that reservoir damage is occurring, it looks at the production rate for the previous year in assessing the anticipated reserve life. Otherwise reserve life is evaluated on the basis of the present year's production rate.

[21] The occurrence of an Arab-Israeli confict is assumed to be an exogenous variable whose value (yes/no) may be set by the user at any time. Information on whether Saudi customers support Israel would be another such variable.

[22] OPEC-established posted price under present contractual arrangements.

[23] To do otherwise would require a sophisticated model of bargaining among OPEC members. It is suggested, however, that later versions of the decision module produce information as to the Saudis' predispositions concerning price and production levels which result from their situation. These would be quite valuable to the anticipated user.

CHAPTER VI. REVIEW OF COMPLETE MODEL BY EX-FLAG OFFICERS AND POLICY PLANNERS

The complete model, consisting of the three substantive modules plus the suggested initial decision module, was presented for review to ex-flag officers and policy planners. The substantive modules were described and the decision module's flow talked through after an introductory discussion of the model's intended purpose and its basic approach. Two types of criticism surfaced during these reviews, the first involving specific errors or omissions within the model, and the second involving problems of a more general nature regarding the model's approach.

Specific Criticisms

Upon being told, in response to a question, that Saudi Arabia planned a tenfold increase in its domestic consumption of refined petroleum products, one respondent pointed out that the construction of refineries to produce the required quantities would require capital investment and suggested that such investment be included in the model. Presumably this would also require keeping track of domestic refining capacity over time.

With respect to the question of possible Saudi budget deficits it was suggested that short- and long-term deficits would probably be handled differently by the Saudis and that they should be kept conceptually distinct within the module. It was also pointed out that a military budget allocation could often be used as a source of revenue to cover a short-term deficit because, in many instances, the delivery time of purchased military equipment may be "slipped." This would not, of course, necessarily remove the deficit, but would delay expenditure (perhaps for a year).[24] The time obtained in this fashion could be used to "find" the money somewhere else.

[24] If a contract were cancelled instead of delivery being pushed back, the deficit might be removed (if enough money were saved).

There was strong criticism of the model's lack of attention to bottlenecks in a developmental economy. In particular, it was pointed out that development, especially industrial development, requires skilled manpower, the need for which did not appear within the model. In addition, even assuming that the model could project manpower needs, there was no way of taking into account either possible bottlenecks in getting personnel trained abroad[25] or the effect of educational expenditures on the number of personnel produced by Saudi schools.

General Criticisms

The general points were raised by the individuals interviewed. First, it was pointed out that the decision module assumed the equivalent of a single decision-maker. In reality the Saudi government has functional ministries, the heads of some of which may be quite influential in making policy within their areas of responsibility. It was suggested that the model could be improved in two ways. First, decision-making within each sector could be more explicitly based on that of the relevant ministry where appropriate. Second, account could be taken of conflicting bureaucratic interests where (and if) they are identified.

The second general point concerned the environment within which Saudi decision-makers function. International political and economic considerations may act as constraints on the feasibility of some Saudi policies. It was recognized that some exogenous influences are included within the model but there was a desire to see additional detail and a more explicit representation of exogenous variables in terms of U.S. and West European policy options.

The last general criticisms raised deal with the way the developmental process was to be conceptualized. It was argued that the process should be

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[25] For example, how many students can be trained abroad and in which disciplines? From what base in Saudi Arabia will the students be drawn?

conceptualized roughly as shown in Figure 3. Items above the decision box represent resource inputs to the process. Below the decision box are sectors to which the resources are allocated. At least two of these sectors (oil and education) provide additional inputs for the process in feedback loops. The current model lacks the ability to see the results of resource allocation to sectors other than oil and the ability to allocate non-financial resources. These were considered extremely important shortcomings from the perspective of a policy planner.

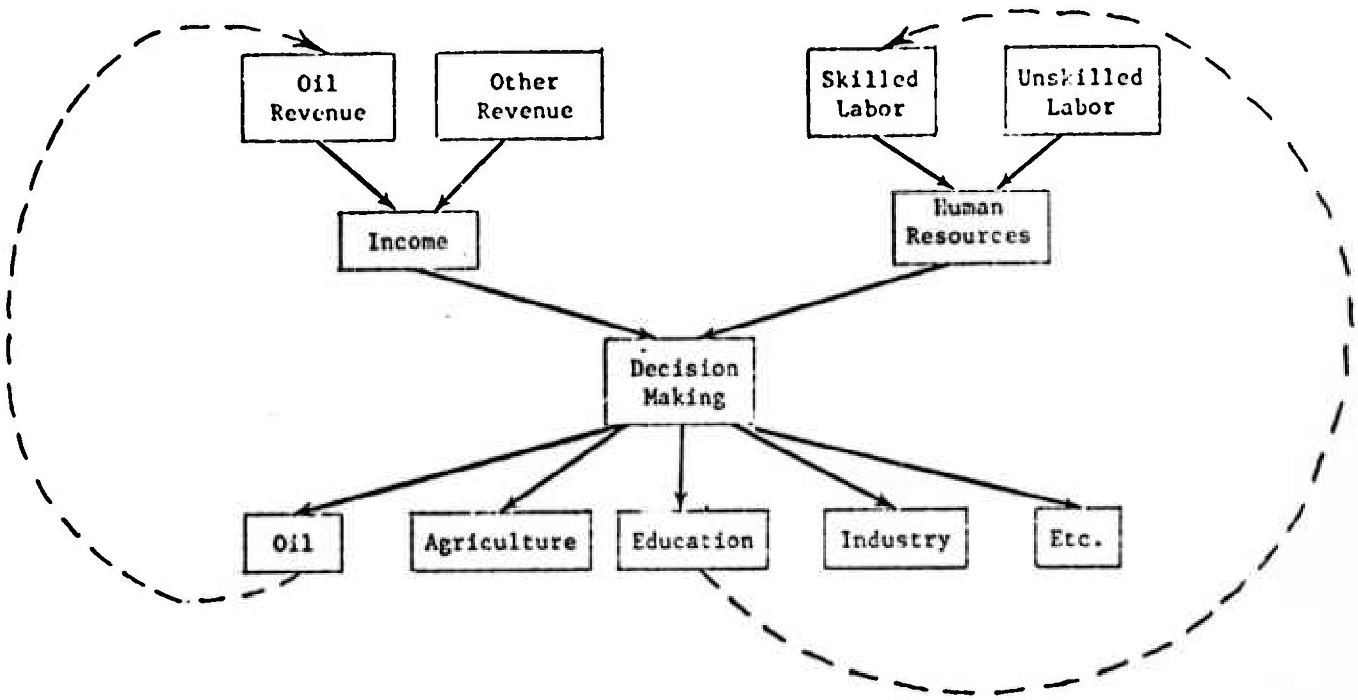

Figure 3. A Policy Planner's View of the Development Process

VII. IMPLICATIONS FOR THE PROJECT'S RESEARCH PRIORITIES

The key problem with the project's model in its present form is its total lack of utility to the policy planner. This point was made rather forcefully when an ex-flag officer suggested that the model simply failed to capture a very critical aspect of the development process. The aspect of which he spoke was the severe bottleneck imposed by a shortage of trained manpower on any effort to develop previously nonexistent (or very small) areas of the economy even when large amounts of capital are available.

In order to capture this problem within the model, the representations of sectors to be developed must contain, in addition to requirements for capital, requirements for trained manpower that are tied to the sector's level of development. The levels of trained manpower available in appropriate categories at any time must be known, and the process that produces trained individuals must be related to the resources (both monetary and human) allocated to it. The human resources module is presently completely unresponsive to the input of resources. Moreover, there is no demand for its outputs (educated and/or trained manpower) elsewhere in the economy.[26]

The implications of these problems for the project's efforts are relatively straightforward but very important. First, a running decision module must be produced, since feedback from policy planners depends upon their seeing a complete model. The structure given in Chapter V of this report should be suitable for an initial effort, provided additional detail is provided in areas where the need was indicated. Second, an industrial sector routine should be produced that contains requirements for both capital and manpower for various levels of development.[27] This sector should specifically

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[26] For an already developed and extremely capital-intensive industry such as oil this is not too important. Capital rather than manpower will be by far the greater constraint on reasonable expansion of production capacity.

[27] As indicated in Chapter V, it is envisioned that the industrial sector routine for Saudi Arabia will be developed within the decision module. Only for a nation with a moderately large industrial sector already in existence would the development of an elaborate and independent sector module be appropriate.

include (as a minimum) both petrochemicals and heavy industry. Third, the human resources module should be reworked. Successful and timely completion of these tasks will result in a model that is not a priori useless to a policy planner. Efforts can then focus on tuning the model in accordance with substantive criticism from policy planners.

Two additional points should be kept in mind while the necessary work is being done. First, careful attention should be paid to the possibility of error in statistics and published information about Saudi Arabia. Every effort should be made to examine as much material as possible, to check for contradictions and convergences, and, if possible, to check Saudi data against figures for similar countries. Second, continued and intensive development and refinement of the decision module should provide the focus for the research tasks, and the research effort should be iterative in the sense that questions about the control inputs to (and interactions between) the substantive modules spur further inquiry into the decision process including its guiding goals and priorities.

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WORKING DRAFT

Modeling for the Future*

Stuart J. Thorson
Polimetrics Laboratory
Department of Political Science
Ohio State University

Warren R. Phillips
CACI, Inc.
Arlington, Virginia

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At least since the publication of Weaver's (1948) well known paper on complexity, many scientists have been aware that the methodological practices employed in studying a problem ought in some sense to be related to the "complexity" of the phenomenon under investigation. Recently Forrester (1969:107) has argued that all social systems belong to the class of complex systems and, as such, "...have many unexpected and little understood characteristics." Some of Forrester's work led to the world modeling project described in <u>Limits to Growth</u>. And, even more recently, Marstrand and Sinclair (1973:89) summarize their critique (with due apologies to Gertrude Stein) of the pollution subsystem of the World models by claiming, "...<u>The Limits to Growth</u> has achieved ... a final simplicity by ignoring all complexity."

It is noteworthy that the concept of complexity is so frequently encountered in discussions of the "holistic" modeling of social systems. Perhaps even more interesting is the relative lack of attention paid to what might be meant by the "complexity" in these context (a notable exception being Nurmi (1974). The purpose of this paper is to consider possible meanings for complexity in a social science context and to discuss implications of these meanings for the development and interpretation of performance measures (e.g., quality of life) for "complex systems."

A useful way to begin may be by summarizing several claims made about complexity beginning with Weaver's argument which first appeared in Weaver (1948) and was later slightly modified in Weaver (1967). Up until the 20th Century, suggests Weaver, physical science was in a period of developing techniques to deal with the analysis of "two-variable problems." Such a problem is illustrated by the way gas pressure (variable one) depends upon gas volume (variable two) in a very major way and upon other variables at most only slightly (at least for a wide range of values of the two variables). Such problems "...are essentially simple in structure, this simplicity resulting largely from the fact that the theories or the experiments need deal with only two quantities, changes in one of which cause changes in the other. The restriction to two variables and in most cases to simple relations between the variables and their first and second derivatives, kept the theoretical system well within the then analytical and computational capacity of mathematics. Correspondingly, these could be simplicity in the experimental basis; and this simnlicity was also a necessary condition for progress at that development of science (1967:26)." Then, roughly at the beginning of the twentieth century, physical scientists and mathematicians began developing and utilizing theoretical tools such as probability theory and statistical mechanics for handling problems with very large numbers of variables. Such problems Weaver terms "problems of disorganized complexity." "It is a problem in which the number of variables is very large, and one in which each of the many variables has a behavior which is individually erratic and may be totally unknown. But in spite of this helter-skelter or unknown behavior of all the individual variables, the system, as a whole, possesses certain orderly and analyzable average properties (1967:29)." The special features of problems of disorganized complexity then are 1) large number of "variables" and 2) the behavior of each "variable" is statistically independent of the behavior of other variables.

What remains, suggests Weaver, is to develop methods for handling problems involving large numbers of variables where the variables "<u>show the essential feature of organization</u> (1967:31)." While this essential feature is not specified in a positive way, presumably Weaver is focusing upon problems where averaging and other statistical techniques are inappropriate or misleading. Such problems he terms problems of "organized complexity." Finally, Weaver suggests that methods of dealing with organized complexity may be especially useful in the social and behavioral sciences.

Weaver's treatment of complexity seems based upon two characteristics of a problem - one quantitative and one qualitative. The first is the number of variables* and the second is the "way" in which the variables are related. As will be seen, these two characteristics have since been frequently employed to index complexity. Note however that together they require that complexity be seen not as a property of "reality" but rather as a property of our description of "reality." Thus an index of the complexity of a referent reality is an index of the complexity of that reality <u>under some description</u>. This point will be returned to, but first there are several more views of complexity similar to Weaver's "disorganized complexity" which ought be mentioned.

Von Neumann (1966), speculated, "It is characteristic of objects of low complexity that it is easier to talk about the object than produce it and easier to predict its properties than to build it. But in complicated parts of formal logic it is always one order of magnitude harder to tell what an object can do than to produce the object. The domain of validity of the question is of a higher type than the question itself." Unfortunately, von Neumann has left unclear the precise meaning of this enigmatic passage. Clearly though, he has in mind that beyond some threshold complexity level our mode of understanding systems changes. Shaw (1970) uses von Neumann's statement to conclude that "any science, like psychology, which desires formal models of highly complex systems, like organisms, will have to consider von Neumann's conjecture a threat to the fulfillment of its explanatory goals."

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* Though as Nurmi (   ) points out Weaver uses variable in a way somewhat different than would a behavioral scientist.

Forrester (1969) defines complex systems as systems with a "high-order, multiple-loop, nonlinear feedback structure." These systems, claims Forrester, behave very differently from the more simple systems we are used to dealing with. Complex systems, for example, are counter-intuitive, insensitive to parameter changes, and have short-term responses which are very different from their long-term responses.

Levins (1970) views complex systems which have many elements and few constraints on the relations between these elements. It is worth quoting at length his thoughts about such systems:

> Suppose we did know the interrelations among all parts of a system and could describe the rate of change of each variable as a function of the others. Then we would have a very large set of simultaneous non-linear equations in a vast number of variables, and depending on so many parameters, the estimation of each of which may take a lifetime .... These equations will usually be insoluable. They would likely be too numerous to compute. If we could compute, the solution would simply be a number. If we could solve the equations, the answer would be a complicated expression in the parameters that would have no meaning for us.

Based upon treatments such as those just mentioned, it is tempting to conclude that complexity is an "intrinsic" characteristic of a system (or, at least, of a system under a description). From such a perspective it would be possible to (metaphorically) develop a complexity "probe" which could be inserted into a system and from which could be read the "complexity" score of that system. However, there are a variety of reasons why such a conclusion is likely in error and that no adequate characterization of the complexity of a system can be given independent of a specification of the class of systems "dealing" with that system. For example, many living species might be said to be facing a less complex environment now than they did thousands of years ago in the sense that, through evolution, many common relational structures may have been "pre-programmed" into their brains. Such pre-programming through evolution or design may well be a key to any system behaving adaptively in a seemingly "complex environment."

As another example, baby salamanders live completely on land for a time after they are born before entering the water in search of new forms of food. Is their ability to swim learned in some fashion; perhaps by imitating other salamanders or by trial and error? Coghill (1929) anesthetized a salamander at birth and kept it in this condition for the length of time salamanders had been observed to remain on land before beginning to swim. After this time had elapsed, the salamander was dropped into water. Even though no learning could have taken place, the salamander was able to swim effectively. The reason for the delay between the time of birth and the onset of the ability to swim was that, as a part of the maturation process, a certain neutral connection had to be made in the salamander's spinal cord. The ability to swim is pre-programmed into the developmental process of the salamander. The effect of dropping a one week old salamander into the pool of water would be very different from that of dropping a five month old salamander into the same pool. Does the complexity of the pool of water change if one animal is able to deal effectively with it while another is not? A more rigorous example drawn from automata theory might make this point more clearly. The problem is to design a Turing maching which can determine whether a string of symbols reads the same backwards as forwards (as in ABLE WAS I ERE I SAW ELBA). Arbib (1969) proves that, for a Turing machine with one reading head the time necessary to decide the problem increases with the square of the length of the symbol sequence. For a Turing machine with two reading heads, however, the time increases only as a linear function of the sequence length. If the complexity of the problem is indexed by the time required to solve it, it is clear that the internal structure of the "solving machine" must be specified rather carefully.

These examples lead to a conclusion similar to that of Nurmi (1974), "Complexity can be viewed as an ontological property of the relationship between the actor and the environment (p. 84)." As long as the focus of study is systems with control structures, complexity must be viewed in a contingent fashion. The next section will suggest implications of this contingent view for theorizing about control structures.

Econometric models are simply mathematical statements of the quantitative relations between variables. Generally these statements are in the form of simultaneous (often linear) equations together with a set of constraints (e.g., certain coefficients must be non negative). In constructing such models, the theorist must specify the form (structure) of the equations as well as the way in which the variables enter the equations. From these equations certain quantitative and qualitative deductions can be made. These include such things as predictions of future levels of endogeneous variables, identification of equilibrium and stability conditions, etc. Figure 1* illustrates the basic mechanism.

Insert Figure 1 about here

The reader is referred to Christ (1967) for a very readable account of the construction of econometric models.

As Christ points out, such models can be guides to choice of policy required to optimize certain utility or welfare functions, if the analyst has a clear statement of the function which is to optimized and also a clear idea of the set of possible policies from which the choice might be made (Theil, 1958). And finally, such a model might be used for simulation studies of the behavior of the system it represents.** There are several dif-

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* Taken from Christ, 1967, p. 104.

** It should be pointed out there there is little to gain from simulations of econometric models when there are analytical solutions available. Four major points are made by Howrey and Kelejian: (1) Once a linear econometric model has been estimated and tested in terms of known distribution theory concerning parameter estimates, simulation experiments that are undertaken to investigate the model as an interrelated system yield no additional information about the validity of the model. (2) Although some of the dynamic properties of linear models can be inferred from simulation results, an analytical technique based on the model itself is available for this purpose. (3) The application of nonstochastic simulation procedures to econometric models that contain nonlinearities in the endogenous variables yields results that are not consistent with the properties of the reduced form of the model. (4) The results derived from the stochastic simulation of nonlinear systems are consistent with the corresponding reduced-form equations. (Naylor, 1971, p. 300) ficulties with this class of modeling, however. Completely simultaneous linear equations, while argued for by some modelers such as Liu (1960) are considered inappropriate because they do not look at the time aspects of the interrelationships. That is, as Wold and Faxer (1957) point out certain pressures affect the growth or stability of a particular variable before others do. Block recursive systems have been developed to deal with this problem (Ando, Fisher, and Simon, 1963). The difficulty with systems of this nature, however, is that forecasts are only as appropriate as the time frame remains short enough to allow for intra-subsystem variance to be more important than inter-subsystem variance.*

Another difficulty in analyzing these models to complex, dynamic issues deal with the frequency with which simplifying linearity assumptions are made. Much of the real world may be nonlinear and while linear models are more tractable than nonlinear ones, realism may require nonlinearity. Two solutions have been put forth for dealing with this problem. The first is to limit the equations to be nonlinear in the variables but not in the unknown parameters. The second is to construct a linear approximation to the model in the neighborhood of the observed values and employ the model to analyze small changes (Netherlands Central Planning Bureau, 1961; Van Den Belt, et al., 1965). Obvious difficulties arise in both approaches, however. The problem of identification in nonlinear systems has not been fully solved and provision must, of course, be made ultimately to avoid working with underidentified equations and systems. One procedure for solving equations in a nonlinear system is by employing ordinary least squares and then using these results as initial approximations to full information solutions (Eisenpres and Greenstadt, 1969). The difficulty of using such methods is

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* A simplified version of this argument was prepared by Fisher and Ando (1962).

that the reality which policy makers wish to deal with tends to be dynamic. If the variables in our model were always correlated in the same way regardless of the mode of system behavior, then they could always be aggregated together into the model in the same way. But if the correlation between variables changes when the model of the behavior of our system changes, then our models must represent the variables separately during each transition mode. The need for separate representation is not well met in linear or nonlinear econometric models. Realization of the importance of this problem in dynamic modeling has led to the understanding that one cannot use correlation coefficients in the building of dynamic models (Brunner and Brewer, 1971). It has also led scholars such as Forrester (1968) to the development of dynamic multiloop feedback systems.

Dynamic Systems Oriented Simulations

Most attempts to generate an explicit model of foreign policy behavior, on the part of academics, have relied upon linear relations among relatively few variables (e.g., linear regression models and factor analysis). These models have certain advantages over mental images of foreign policy interactions since they have explicitly specified sets of assumptions about the relations between these variables which can be checked by resorting to data analyses. These assumptions of linearity provide fairly accurate short-term (several years) projections since any curve, over a short enough interval, can be approximated by a straight line. However, the longer into the future the projections are made, the greater will be the likely error, just as in the case for trend extrapolation. In designing long-term planning systems, the analyst must be prepared to work with non-linear systems. One problem with non-linear systems is the lack of methods for solving such systems analytically. However, solutions can be reached through the use of computer simulations.* These simulations provide information about the overtime implications of the defined alternatives. Moreover, they will allow the manipulation of the variables and relations to test the relative, long-range impacts of various policy alternatives. These simulation models to be useful to the policy planner require that the variables be categorized as to whether they are manipulable or non-manipulable and as to whether they are exogenous or endogenous:

1. Manipulable variables are directly controllable by the policy maker.
2. Non-manipulable variables may vary as functions of other variables in the models but are not directly controlled by the policy maker's actions.
3. Exogenous variables effect but are not affected directly by relations specified in the system.
4. Endogenous variables effect other variables and are in turn affected by other variables in the system.

A set of variables representing each subset of manipulable exogenous, non-manipulable endogenous, and non-manipulable exogenous variables can be posited. The variables and relations could, in part, be identified by people involved in the policy process and could be used to construct simulations.

Thus, within the system, each variable would be in one of the following vectors:

$M^x i$ = vector of manipulable exogenous variables

$U^n i$ = vector of non-manipulable endogenous variables

$U^x i$ = vector of non-manipulable exogenous variables

These variables are related by some set of relations, f. Thus:

$$f(M^x{}_i, U^n{}_i, U^x{}_i) = \text{"The System"} \quad (5)$$

* See the very interesting debate between Nordhaus (1973) and Forrester, et al. (1974) on the use of such an approach.

Models of this nature consist essentially of a large set of mathematical equations which are programmed into a computer. Projections into the future are simply the implications of the assumptions on which the equations rest. The value of extrapolation is determined completely by the validity of the assumptions that went into the building of the model. They drive the results mechanically. Their validity, however, depends on the descriptive adequacy of "the system" and on the empirical domain to which the model is applied. The adequacy of the system is governed by two considerations: (1) available knowledge of how the included variables interact raises a serious question as to the state of preparedness for this type of model of most of the social sciences today. The other condition relates to the presence of all variable factors that significantlyzaffect the interacting behavior of the other variables. This particular aspect of dynamic modeling leads us to question the adequacy of the approach. We can take up these two criticisms in their order.*

Social scientists do not yet possess a body of theory sufficiently developed and tested to permit the confident specification of variables to be included, form of equations to be used, and appropriate lags for each variable prior to the estimation of parameters entering into equations. Existing theory offers some guidance, but it is the most fanciful kind of wishful thinking to believe that it offers much guidance in the above respects for many of the political problems which face decision makers in the policy oriented future. This being the case, it is obvious that any effective testing and estimation does require veryzlarge numbers of observations. This would be true even if the observations to be used were generated by experiments

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* For a comparison of a number of modeling techniques and their application in political economic forecasting see Heiss, Knorr and Morgenstern, Long Term Projections of Power (1973).

arranged according to the best available knowledge about experimental design.*

Perhaps the greatest challenge in mathematical modeling and simulation is to select a model large enough to represent a real situation realistically, but small enough so that it can be tested by experiments and observations. Given our state of knowledge about the relations between numerous variables, this leads us quickly into difficulty. One solution frequently used in international relations has been to move to highly aggregated forms of data. But such highly aggregative series do not begin to contain enough degrees of freedome to permit extensive testing and estimation. This would be true even if the observations in such a series resulted from well-planned experiments. In fact, most available aggregative series are highly auto-correlated, highly multi-colinear, are frequently poor measures of what we want to measure and do not measure short run developments. They are involved in an operating system involving many relatively rapid feedbacks. All this only compounds the already apparent drawbacks of estimation and testing based only on highly aggregative time series.**

This issue is perhaps best handled by E.A. Singer (1960). He argues that reality is an ideal, and unobtainable description of the world. But like all ideals, it can be approximated. A formal system is an approximation if it meets certain requirements: It must be consistent, the data must be statistically in accord, it must be rich enough to include space, time, motion, mass, mind, group, and value. It must also be significant in the sense that it directs inquiry into its own deficiencies, so that a better approximation

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* Several new articles are appearing which provide alternative methods for estimating parameters from empirical data for this type of model building. See, for instance, Hauser and Goldberger, 1971.

** The classic reference is Theil, 1954.

is made possible. In other words, its language and rules must include criteria of better and worse approximations, i.e., degrees of realism.

Singer is certainly not claiming that all practical work must contain the whole of reality. Rather, he argues that each researcher will construct a subsystem adequate to his own needs for a particular period in time. But the lines of communication have to be kept open in the sense that it is always relevant to ask whether two subsystems should not be combined in order for a single researcher to cover larger periods of time or for several researchers to answer several intertwined sets of problems. There may be a temporary way out of this problem. Returning to Figure 1, our stylized schematic and development of a model, in which inputs to the model in the form of exogenous and lagged endogenous variables and outputs in the form of current endogenous variables were the organization framework for discussing models. Another possibility involves describing the system in automata theoretic terms. Following Arbib (1964) such a specification involves:

$$\text{The System} = (U, Y, X, \lambda, \delta)$$

where:

U is a finite set (the set of inputs partitioned as in equation (5))

Y is a finite set (the set of outputs)

X is a finite set (the set of internal states)

$\lambda: U \times X \rightarrow X$ is the next-state function

$\delta: U \times X \rightarrow X$ is the next-output function

Such systems are assumed to work on a discreet time schedule so that if at time t it is the state x and redeives an input u then at time t plus one it has changed to state $\lambda(x,u)$ and emits output $\delta(x,u)$.

Clearly it is desirable to identify what the state transition functions are if we wish to estimate future shifts in behavior in our policy problem.

This requirement can be illustrated by a simple example. Consider the behavior of a "bully" nation. Suppose it is capable of being in only two internal states--it either is stable (S) or unstable (∿S). Further, it is capable of emitting and sensing only two sorts of behaviors--aggressive (A) and non-aggressive (∿A). Thus we have:

u: {A,∿A}

y: {A,∿A}

x: {S,∿S}

Since the nation is a bully, it will behave aggressively whenever it can. And yet the only time a bully does not aggress is when it is aggressed upon and in a weak (in our terms unstable) state. Thus we can write y= (x,u) as in Table 1.

Table 1

Input (u)	State (x)	Output (y)
A	S	A
∿A	S	A
A	∿S	∿ A
∿A	∿S	A

As can be seen the output of the bully nation is entirely deterministic. Further, since even a bully becomes unstable when aggressed upon, $\underline{x} = \lambda(\underline{x},\underline{u})$ can be written as in Table 2.

Table 2

Input (u)	State (x)	New State (x)
A	S	∿S
∿A	S	S
A	∿S	∿S
∿A	∿S	∿S

All this most likely seems both absurd and simple. However, further suppose a political scientist is watching the bully nation and trying to relate its behavior (outputs) to the behavior it receives (its input). What will he see?

First of all, he will generally ignore the internal structure of the system and simply relate inputs and outputs. Thus he might watch the bully over a long period of time and note that non-agressive inputs always are followed by aggressive outputs on the part of the bully. However, he would note, aggressive outputs are preceded by aggressive inputs only about one half of the time. Therefore, he writes an article in which he proclaims two general laws.

law (1) $P(y = A|u = \sim A) = 1$

law (2) $P(y = A|u = A) = 1/2$

Of course, by this time the world is getting rather sick of the bully's behavior and commissions our political scientist to recommend a policy toward the bully (this policy above, the optimal policy would, of course, be to always behave in an aggressive way toward the bully nation which would, according to law (2), guarantee that 1/2 of the bully's responses would be non-aggressive.

Note that our mythical political scientist, like so many of us, ignored the internal state of the bully nation. As a result, he was forced to state his laws in probabilistic terms and to conclude that the "best" that could be done was to reduce $p(y = A)$ to about one half.

However, by referring back to the transition tables, it can be seen that the bully can be made to act in a completely non-aggressive way. Suppose first he is initially in state $\sim S$. Then by always behaving in an aggressive way toward the bully, the bully will never respond in an aggressive way. If, on the other hand, he is initially in state S, then he will respond in an aggressive manner no matter what you do. However, by threatening him, you will force him into an unstable state and therefore continuing aggressive acts will result in no more threats from the bully.* Thus, paying attention to internal states, it is possible to eliminate references to probabilities and to suggest a policy which will result in at most one aggressive behavior by the bully. While in this example ignoring internal structure did not result in "wrong" policy advice, it is possible to construct a slightly more complex example for which it would.**

The important point here is that developing descriptive theories of policy behavior requires paying close attention to the internal structure of the foreign policy generating mechanism as well as to that of the environment (domestic as well as international) in which the mechanism is imbedded. We need to know how inputs affect internal states and how inputs together with internal states determine outputs. As Halperin and Kanter (1973, p.3) suggest, "....the scholar requires an understanding of a nation's domestic political structure and of its national security bureaucracy in order to explain or predict the foreign policy actions it will take." At this point in the development of research in social science, we also need, however, to identify the differences in a finite set of states or subsystems which have been identified as potential explanatory structures for understanding of policy problems. We need also to better understand the implications of policy actions in each state of the system (thus, we need to devote understanding of $\delta: S \times X \to Y$.

This approach is based upon finite state automata theory and has a strong argument in its favor. That is, it requires the precise specification of the functional relationships between endogenous and exogenous variables for producing estimates of the output.

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* Though such a policyzmight result in your becoming a bully.

** For example, see Kanter and Thorson (1972).

What has been presented here are three alternative approaches to modeling major policy problems for the future. It is suggested that econometric models and dynamic forecasting models both are in need of continued development. Both have difficulties. The former suffers from an inability to deal with large scale, long-range forecasting and decision oriented problems. The latter suffers from an inability to provide significant validation checks on the empirical validity of subrelations within the model. The solution is to move to partial answers based upon the notion that the structure of our theory undergoes shifts given both the current state of the system and the particular shocks in the form of input variables that the system is experiencing. But once we have such a model we still are left with a series of general questions which must be addressed by all such models. Brewer and Hall (1972) suggest the following checklist.

1. Is the distortion between the model outputs and what the policy maker is looking for so large that the model is rejected out of hand? Can this be reduced? At a reasonable cost in time, effort, and money?

2. Are the model's output and input generally intelligible; are they in a form that is familiar to the policy maker?

3. Does the model offend "common sense?"

4. Are elements of the identified question excluded in the interests of generalization or precision?

5. Is the model static and descriptive in the interest of simplification?

6. Is it possible to include submodels or to change individual behavioral relationships that appear to have a bearing on the policy questions without destroying the processing or the logic of the model or without significantly increasing its operating cost?

7. Are relevant variables, as determined empirically and by virtue of sensitivity testing, omitted in the interest of precision or expense?

8. Is the model able to predict, through reconstruction, the time series upon which it is formulated? Has it been able to predict time series from the reference context developed subsequent to the model's formulation?

9. If there are known structural changes in the empirical context, are provisions made in the model to capture these? I.e., If there are increasing numbers of disaggregations, changing parameters, or precipitating discontinuous events in the context, are these taken into account? Or, are these events ignored or assumed away?

10. Are the policy interpretations of various model entities, structures, and recommendations, consonant with the ethical-moral and professional standards of the policy makers and the affected population? (Brewer and Hall, 1972: 18-19).

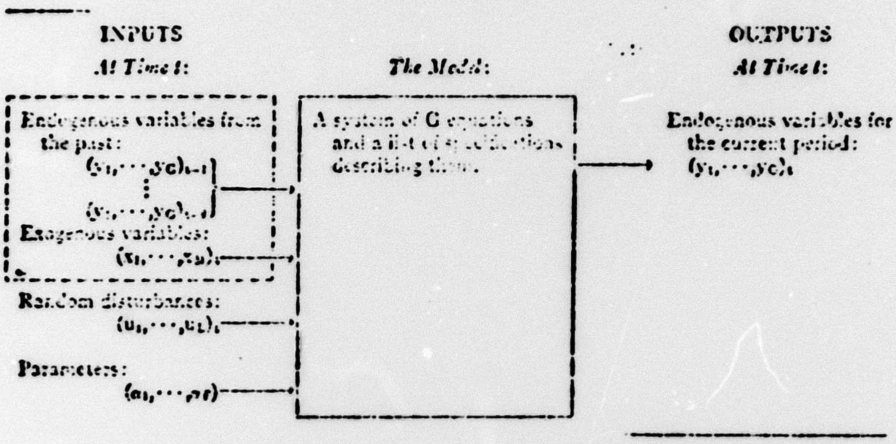
INPUTS
At Time t:
Endogenous variables from the past:
Exogenous variables:
Random disturbances:
Parameters:
The Model:
A system of G equations and a list of specifications describing them.
OUTPUTS
At Time t:
Endogenous variables for the current period:

Figure 1.

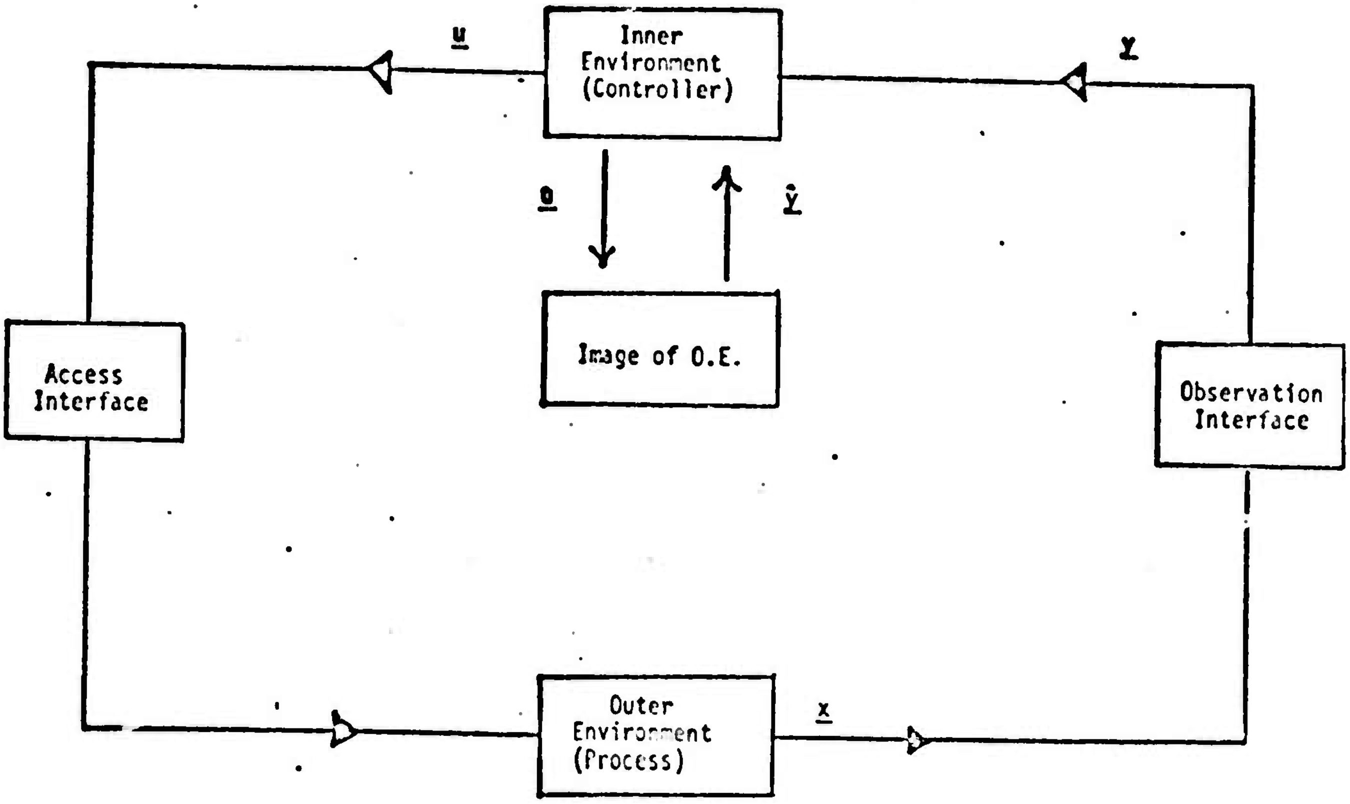

Figure 1   Artificial System Structure

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PS:  LRCC74
STI: (NIL  NIL  NIL  NIL  NIL  NIL  NIL  NIL)

1:   (STOP) → END
2:   (REQUEST) → (OUTPUT  "RESIGNATION", STOP)
3:   (MARK,MARK,MARK,MARK) → (OLD(**),REQUEST)
4:   (FOOD SHORTAGE,FISCAL IRRESPONSIBILITY,NEGATIVE FOREIGN
          COMMENT BY AN ALLY) → (OLD(**),REQUEST)
5:   (FOOD SHORTAGE) → (OLD(**),MARK)
6:   (SUPPORT OF RADICAL FOREIGN CAUSES,NO ACHIEVEMENT) →  (OLD(**),MARK)
7:   (SUPPORT OF RADICAL FOREIGN CAUSES,SFRC,SFRC,SFRC) →  (OLD(**),
          FISCAL IRRESPONSIBILITY)
8:   (FISCAL IRRESPONSIBILITY) → (OLD(**),MARK)
9:   (NEGATIVE FOREIGN COMMENT BY AN ALLY → (OLD(**),MARK)
10:  (BAN CIGARETTES or BAN ALCHOHOL or BAN LUXURIES) →
          (OLD(**),ORTHODOXY)
11:  (ORTHODOXY,ORTHODOXY,ORTHODOXY,ORTHODOXY) → (OLD(**),MARK)
12:  (FOOD SURPLUS,MARK) → (OLD(**))
13:  (SUPPORT RADICAL FOREIGN CAUSES,ACHIEVEMENT,MARK) → (OLD(**))
14:  (INCREASE IN SKILLED LABOR,MARK) → (OLD(**))
15:  (SADAT HAS TROUBLES,MARK) → (OLD(**))
16:   → READ

* SFRC = SUPPORT OF RADICAL FOREIGN CAUSES
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Figure 2   A Simplified Production System

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