Cognitive Criteria for Structuring System Dynamics Models

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ABSTRACT

This paper discusses the development of cognitive criteria for use in guiding the problem definition phase of System Dynamics modeling. The System Dynamics modeling process is presented as currently defined in the literature. The problem definition phase of the process is then isolated because of its overriding influence on model structure. Topics relating to information, information processing and group decision making are discussed and the shortcomings of human judgment and inference are identified. These shortcomings are related back to the tasks required for problem definition and criteria are identified which can serve as guidelines for the development of cognitive aids for structuring System Dynamics models. The paper closes with a brief discussion on operationalizing the concepts of cognition, creativity and social interaction as tests of the relative value of these criteria.

INTRODUCTION

Literature in System Dynamics presents a multi-staged process for use in selecting model elements and specifying model structures (Roberts, et al., 1983; and Randers, 1980). It is widely accepted, however, that this process will not provide mechanistic rules for selecting and structuring model components, for this is an activity commonly regarded as the "art" of modeling. While we agree that problem formulation and model structuring can be considered artistic and therefore not amenable to mechanization, we believe that the entire process can be better facilitated by taking into account the information processing capabilities of individuals and groups.

It is important to recognize that model structures, once complete, become decision environments. As such, a model may be conceived of as a "cognitive aid" which reflects an enhanced but unique understanding of the problem situation, both guiding and constraining the alternative courses of action. Since model structure has such a significant impact on the subsequent phases of problem solving, appropriate criteria to guide the structuring process need to be developed. This need becomes even more apparent when the initial phase of modeling involves the direct participation of a number of people including the client, and where communication and issues of accountability become important. The goal of this paper is to present the tasks required for guiding and organizing these tasks so that the cognitive capabilities and limitations of individuals are taken into account.

To determine which specific tasks to consider the guidelines provided by Randers (1980) and by Roberts and her colleagues (1983) will first be combined to give a full account of the decision process employed by SD modelers. That portion of the process which relates to problem definition will be isolated for further study. Then, to develop criteria for guiding problem definition behaviors, topics related to information and information processing will be discussed with respect to 1) the types of information used by modelers, 2) the manner in which the information is processed for decision purposes, and 3) the cognitive pitfalls common to such decision situations. Since modeling under socially complex conditions will often require that several individuals participate, group process will also be discussed as it relates to decision making. The discussion will close with a set of proposed criteria which are thought helpful in enhancing both the cognitive and group processes previously identified. Such criteria may therefore serve to guide the task completion behaviors which collectively lead to a problem definition.

THE MODEL STRUCTURING PROCESS

Randers (1980) identifies four stages of model construction; they are conceptualization, formulation, testing, and implementing. The conceptualization stage is facilitated through application of the SD paradigm and the formulation stage through use of the DYNAMO computer language. Testing is performed both logically and empirically and may require the iteration of stages one and two. The implementation stage involves model application for policy analysis, for sensitivity analysis, and for generating potentially useful information.

Regarding the initial aspects of model development, Randers assumes a relevant problem to exist as a prerequisite for model conceptualization. The conceptualization stage is therefore presented as the most critical, for it is here that the basic assumptions concerning the behaviors to be modeled and the components used in doing so are developed. Procedurally speaking, Randers calls first for a definition of the reference mode, i.e., a description of the time development of interest; and second, for the identification of basic mechanisms, i.e., the most fundamental set of interrelated components which produce the reference mode. A time horizon is necessarily identified and made explicit in the reference mode, and both the system boundary and the required level of aggregation are defined through identification of the basic mechanisms. From this, the modeler formulates a flow diagram if desired and writes the specific code required by the DYNAMO compiler.

Roberts and colleagues (1983) identify a model building process having six phases: they are problem definition, system conceptualization, model representation, model behavior, model evaluation, and policy analysis and model use. This is nearly identical to that proposed by Randers but is more explicit with respect to identifying both the definition of the problem and the analysis of model behavior as separate stages or phases in the process. Important and distinguishing aspects of the Roberts presentation are first, the stated need for modelers to concern themselves with an initial problem definition phase, and second, the ensuing discussion on analyzing less-structured problems.

Four critical components of the problem definition phase are introduced which essentially add detail to Randers' conceptualization stage and introduce elements of real-world constraints into the process. These components are the "perspective", the "time horizon", the "reference mode", and the "policy choices". The reference mode is described by taking a particular modeling perspective, i.e., an explicit assumption of a point of view, and deciding on the modeling time horizon or time period of interest. Only by combining these two concepts can one clearly identify the reference mode, i.e., the time development of interest. The fourth component, the policy choices, requires that initial proposals for change be identified. They must appear realistic in the face of any social, political, legal, or other constraints which could significantly influence future action. These constraints become part of the modeler's conceptualization and influence the form and content of the resulting model.

These two descriptions of the modeling process can be combined into what Passini (1984) refers to as a "decision-plan". Figure 1 illustrates this System Dynamics decision-plan and represents the process in a way useful for distinguishing decisions, tasks, and behaviors and for relating each to one another and to the process as a whole. Briefly stated, decisions give birth to tasks which in turn foster behaviors designed to complete each task. For example, the SD modeler's decision to define the reference mode generates two tasks: first, identifying the perspective, and second, identifying the time horizon. Each of these tasks implies certain behaviors designed to complete them.

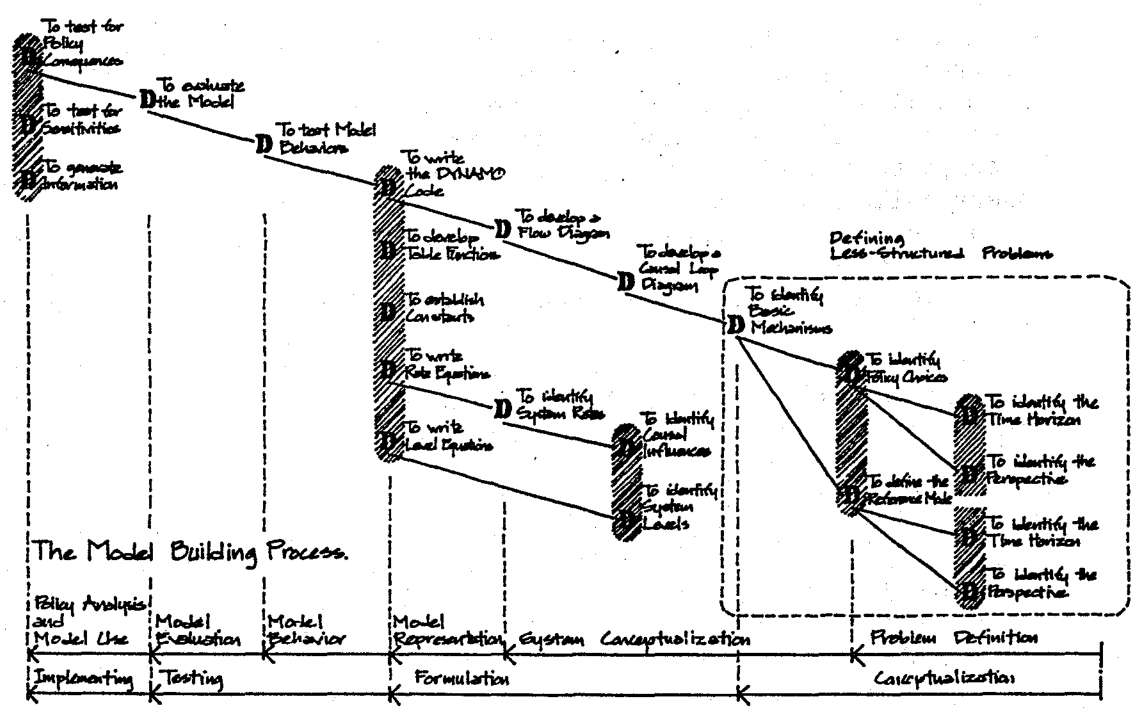

Figure 1. System Dynamics Decision-Plan.

The actual development of a decision-plan may therefore be thought of as both a task-generating activity and a solution-generating activity (Passini, 1984). The decisions in figure 1 read hierarchically from left to right and collectively generate the set of tasks one then attempts to accomplish. The tasks, which read in reverse order from right to left, illustrate the sequential nature of the solution-generating activities or behaviors which eventually lead to the completion of the most basic of tasks, i.e., test for policy consequences.

Once a decision-plan has been specified, the behaviors invoked enroute to a solution require modelers to use various types of information for each task completion exercise. The more formalized a process and its many tasks become, the more guided are the behaviors. Hence, appropriate information is easily identified and made readily available, and the manner in which it is to be used is clearly understood. In SD modeling, those tasks corresponding to Randers' formulation, testing and implementing stages have become quite formalized, with solutions readily available both from the formalisms defined by the DYNAMO computer language and from prior experiences in model testing and implementing. However, for the majority of tasks corresponding to the conceptualization stage, or problem definition phase, similar formal solution procedures have not been developed. These subtasks remain rather vague and therefore problematic. The types of information which should be brought to bear on these tasks and the manner in which these need to be integrated or interpreted are not at all clear. The result is that the behaviors invoked for purposes of problem definition are not given adequate guidance.

In order to develop criteria useful for guiding modelers through the various tasks on the decision-plan, the types of information and corresponding strategies for information processing will be presented first. These will be based on the cognitive limitations and inferential biases inherent in human judgment and decision making.

INFORMATION AND INFORMATION PROCESSING

There are three types of information inputs into the problem definition phase of modeling; sensory information, memory information and inferred information (Passini, 1984). Sensory information is that obtained through direct sensory contact while memory information is evoked from past experience. Memory information once went through the process of being directly perceived or sensed. The distinguishing characteristic is that at a given moment memory information can be obtained without or independent of sensory inputs, while sensory information cannot. In this way, sensory information is directly related to the environment or the setting within which one must operate whereas memory information is at least one step removed from this setting. Inferred information is that obtained from any combination of sensory and memory information where the decision-maker manipulates one or the other based on the influences each brings to the situation.

Corresponding to each of these information types are three task situations. The first is when sensory information is itself sufficient to complete a task, the second is when memory information is also required, and the third is when information must be manipulated to arrive at some inference. A fourth situation frequently encountered is when little or no relevant information seems available. For purposes of SD modeling and particularly for defining less-structured problems, individuals are most likely to be in situations where both memory and sensory data are combined and an inference made, or where little or no information is available either from one's memory or from the setting. And when in the latter situation, individuals will initiate a search process for information acquisition. Thus, modelers typically find themselves in two of the four task situations and subsequently use either of two broad strategies for guiding behaviors and decisions. They will employ an inference strategy when information is both available and considered adequate, or they will employ a search strategy to acquire the needed information. The search strategy is performed until an inference becomes possible and is considered acceptable. Indeed, as individuals search they also infer and when satisfied with their inference the search is often ended. Therefore, the inference strategy is ultimately employed in all modeling behaviors.

When engaged in inference, people use two broad types of intuitive implements, knowledge structures and judgmental heuristics. Knowledge structures relate to memory information and include sets of beliefs, theories, propositions and schemas, all of which people acquire through experience. Structures such as these are used to label, categorize and form expectations about objects or events and to suggest appropriate responses to them. Judgmental heuristics are cognitive strategies used to reduce complex inferential tasks to simple judgmental operations. Nisbett and Ross (1980) suggest that judgmental heuristics are the chief determinants of the arousal and use of the various knowledge structures.

Three judgmental heuristics are identified by both Nisbett and Ross (1980) and by Einhorn and Hogarth (1982); they are the "representativeness" heuristic, the "availability" heuristic, and the "relevance" heuristic. The representativeness heuristic is used to reduce inferential tasks to simple similarity judgments. The availability heuristic is used to judge frequency, probability and even causation, with such judgments based entirely on the extent to which applicable information is readily available in one's memory. The relevance heuristic is used to assign inferential weights to data in proportion to their salience and/or vividness in one's mind. These heuristics generally result in successful evaluations of everyday life complexities. However, the same mechanisms are also used inappropriately and without adjustment. Unfortunately, individual decision-makers are not typically aware of the natural limits on their cognitive abilities and, hence, of the possibility for biased inferences from the use of these heuristics.

Indeed, researchers have found rather severe and systematic shortcomings in people's ability to make judgments and inferences when confronted with complex problems and data structures (Tversky and Kahneman, 1978). Collectively speaking, judgmental errors can be grouped into two broad categories; first, those involving the use of available information such as base rate data, i.e., information about the probability that the variables - objects, individuals, or events - will take a specific course of action; and second, those involving the use of information previously acquired as reflected in one's knowledge structures. This second category of inference uses cause and effect information, i.e., the probability that a specified course of action will produce a specified outcome.

When making inferences using base rate information, people will tend to underutilize it to the degree that they consider it of relatively lesser quality or simply inapplicable to the decision. Quality and applicability is often inappropriately assessed due to inattentiveness to normative principles.

When inferring about cause and effect, individuals' knowledge structures will greatly influence their predictions. The literature clearly documents what is referred to as the perseverance tendency, where one's beliefs tend to persevere for various reasons beyond the point at which behavioral norms call for change (Nisbett and Ross, 1980). People have been found to adhere to preconceived beliefs in the face of evidence that ought, rationally, to weaken or even reverse their belief (Hovland, Janis and Kelly, 1953). People also tend to assess new information asymetrically, meaning that an individual's apriori expectations and theories tend to bias the detection of covariation or relationships among base rate information (Nisbett and Ross, 1980), and therefore bias any inferences made. Thus, opinions once formed are slow to change in response to new information. It is interesting to note that scientists have also been observed adhering to theories well past the point justified by evidence (Mahoney, 1976).

In a similar manner, individuals recognize the relevance of data which confirm prior held hypotheses more readily than those which disconfirm them and, in this way, tend to search for such data in evaluating their hypotheses (Wason and Johnson-Laird, 1965). Furthermore, involvement in the process of causal explanation or hypothesis formation has been shown to influence the plausibility or subjective likelihood individuals place on the explanation of events (Ross, et. al., 1977). And last, causal schemas appropriate to some settings are often inappropriately applied to others (Einhorn and Hogarth, 1982). People are therefore prone to making inappropriate predictions.

Such shortcomings in judgment and inference pose real threats to modeling in which judgmental data are used. With particular regard to the problem definition phase of SD modeling, two main issues become apparent. The first is that individuals are likely to come to the modeling exercise with predetermined notions of the problem and its causes. When the problem conditions are complex and difficult to define, such premature frames of mind may so dominate the definition phase that new knowledge and new understandings cannot be brought to bear on model form and policy choice. The second issue involves the use of information and the tendency for biased inferences through the inappropriate use of judgmental heuristics. Information which is both relevant and important may be ignored entirely or may be given inappropriate weights.

Fortunately, however, research does support the notion that the tendency to persevere in one's beliefs can be countered by providing individuals with an opportunity to alter their hypothesized cause and effect relationships through the timely intervention and proper presentation of relevant information. An individual's theories and beliefs are subject to change, but such seems to require information which is concrete, sensory, and personally relevant (Nisbett and Ross, 1980). If relevant base-rate information is to have any impact, it should be presented in a clear and vivid manner. In addition, causal explanations for the base rate information presented will increase the likelihood of it being used (Einhorn and Hogarth, 1982). And when individuals go beyond making one-time-only judgments and instead are allowed to manipulate and act on both the data and the model, i.e., if the "action" component is present, they may learn how to better use information and to make more informed judgments (Einhorn and Hogarth, 1982).

GROUPS AND GROUP PROCESS

This last discussion centers on group processes and is thought equally important in terms of the problem definition phase of SD modeling. This is because one of the advantages of SD is its suitability for collective decision making where experts and laypeople are able to participate in various phases of the modeling process. While group decision-making will generally influence the quality of decisions in a positive direction, both advantages and disadvantages exist and need to be discussed as they relate to cognitive processes.

Groups can first be characterized by the various dispositions of their members. Each will possess what Checkland (1981) refers to as a worldview which is composed of three elements: cognitive representations, evaluations, and ideals. In the group decision making context there is no pre-given worldview but one which is produced by the active participation of individuals and through negotiations concerning differing interpretations of reality (Checkland, 1981; p. 276-277). These worldviews may manifest themselves in terms of knowledge structures acquired through professional affiliation and/or in terms of one's motivations.

In addition to adhering to a unique worldview, each group member may utilize a particular cognitive style in their approach to problem-solving (Mitroff and Turoff, 1973), with each based on an internally consistent inquiry system, and with no single style being the correct one. When dealing with unstructured problems the adoption of only one of these inquiry models is not justified, hence, the use of groups and group process to guarantee alternative cognitive styles.

Groups possess information processing capabilities which improve decision quality beyond that normally achieved by individuals. Gibb (1951) found that the number of different ideas generated by a group was greater than that of any one individual. In addition, groups have been found superior to the individual when the task involves a search process. There is a greater probability that one of several people will produce needed information than that a single individual will do so (Collins and Guetzkow, 1964). These same authors found groups to be superior in producing accurate interpretations because a wider variety of views are voiced and because when opposing views are considered, group process can be structured in order to guarantee some amount of anonymity which in turn allows for the freer flow of ideas and the joint assessment of all opposing views without individual hostilities forming.

Groups also exhibit certain overt behaviors. A group will always be responding on either of two levels; 1) responding to the problem agenda or the business at hand, or 2) responding to the hidden agenda, i.e., the motives, desires, aspirations and emotional reactions of individual participants. Regarding the hidden agenda, group perceptions of such factors as prestige, power and education often serve to unduly influence interaction, whereas each individual's self-awareness, their ability to listen and the breadth of social acceptance each displays are factors which can positively influence group success (Patton and Giffin, 1973). Groups therefore exhibit both defensive behaviors which diminish effectiveness and supportive behaviors which act to improve effectiveness.

Several problems relating to behaviors and processes in group situations have been identified by Patton and Giffin (1973). The first is that all too often either the group facilitator or the individual participants assume that their concerns are shared by others. But since the concern brought to the group session strongly shapes one's responses on many levels of interaction, it is imperative that mutual concern not be assumed. Rather, it should be verified by attempts to determine if it exists and to clarify what these mutual concerns are. If mutuality of concern is not present other means of promoting cooperative behaviors should be utilized.

A second problem which often plagues groups is a lack of specific information. The ability to recognize this is key, for individuals are often unwilling to admit that they are relatively ignorant on certain subjects. In a similar vein, groups are often observed behaving with such conformity that information which is relevant but yet unmentioned will not be brought to the discussion. Group ideation techniques may be appropriately applied to increase the amount of information made available and thereby unleash the superior ability of the group to identify and interpret wide ranging data and opinion.

A third problem is that groups may sometimes prematurely focus on a narrowly defined perspective or emphasize possible solutions well before it is appropriate to do so. Members may take stands based on their own knowledge structures well before the problem has been adequately defined. And while the goal or solution being emphasized may indeed be that which is eventually adopted by the group, it is again important that each member feel that their inputs have been decisive in the selection process.

A fourth problem is that people assume that truth, and therefore consensus, will result from adequate discussion even if entirely informal in character. Particularly when the information content of the modeling exercise is complex, more formal aids to cognition need to be applied to integrate the information made available, to reduce it to a simpler form for decision purposes, and to help the group achieve a high degree of consistency in its logic and decision process.

CRITERIA FOR MODEL STRUCTURING

Having identified the limitations in individual judgment and inference as well as the problems inherent to groups and group process, criteria can now be established to guide model structuring. The specific tasks to be completed are 1) the identification of the perspective, 2) the identification of the time horizon, 3) the establishment of the reference mode, 4) the identification of the policy choices, and 5) the definition of the basic mechanisms. The following discussion summarizes each and presents the recommended criteria.

PERSPECTIVE

When identifying the perspective, or the group frame of mind, it is important not to assume that participants have shared perceptions. Instead, the group should attempt to clarify and determine the different perspectives that may exist. In establishing a shared perspective it is also important to avoid a premature focus on a single item or on a small set of items as a basis for mutual agreement. Instead, the group should accomplish the task of identifying the perspective through a process which generates an exhaustive list of concerns, issues or problems brought to the meeting by the various participants. The procedure used should not allow any single individual to dominate the discussion and if possible should guarantee anonymity. Each participant must be made to feel that their inputs are critical.

From the standpoint of the individual within a group, avoiding an early focus on a narrowly defined perspective will promote flexibility in the application of knowledge structures. Participants can therefore be expected to remain open to new information and to different ways of interpreting the knowledge they possess and that which they may acquire. Providing such guidance to individual thinking has been shown to feed back to the group and to promote more effective behavior through the open, communicative and generally supportive actions of its participants (Patton and Giffin, 1973).

The criteria which should govern behaviors when identifying the perspective are as follows:

1. Aid the individuals to externalize their dispositions regarding the problem situation by probing them to describe the situation in their own terms.

2. Ensure equal participation by the group members.

3. Avoid premature closure on a single perspective:
   i. Promote broad thinking, idea generation.
   ii. Withold judgment, do not eliminate or limit the scope of viewpoints.
   iii. Entertain opposing viewpoints.

When these criteria are applied the outcome of this task will be a number of issues and viewpoints which may or may not converge on a coherent perspective. Before such convergence is even encouraged, the individuals in the group need to explore the underlying assumptions and implications of their statements. This may be accomplished by discussing the time horizon, the reference mode and the policy alternatives corresponding to the perspectives that are generated in the subsequent tasks.

TIME HORIZON

When identifying the time horizon the group will attempt to decide how far into the future to continue their analysis. This will be dependent on the perspectives being discussed and on the quality of the information which can be brought to bear on the situation. Better information allows for better predictive capabilities which may in turn make participants more willing to commit themselves to inferences further into the future. At this stage, the types and the relative quality (availability and certainty) of information which is supportive of the various perspectives need to be defined. For each perspective the behaviors of interest and their associated assumptions are stated. Next, the information types needed to justify/operationalize the perspectives are defined. Then a tentative, judgmental evaluation of their quality and availability is made. Finally, based on these investigations, a time horizon is to be assigned to each perspective. The main criteria for carrying out these subtasks are:

1. Further clarification of assumptions and implications of each perspective.

2. Establishment of a group language based on a common understanding of terms.

3. Identification of the data requirements for future stages.

4. Avoiding the elimination of and a premature closure on any of the perspectives at an early stage until the subsequent tasks are accomplished.

REFERENCE MODE

The "reference mode" is the time dependent behavior of interest and may refer to either an existing or a desired state. In establishing the reference mode the group will generate a number of scenarios and graphs corresponding to each perspective based on the outcomes of the previous task. In order to record the initial perceptions as a base-line, the group should complete this task once, using only the information available to the individuals without initiating a search. Then appropriate base-rate information should be acquired and the group should modify the reference mode. This can only be accomplished if the reference mode involves the past behavior of the system.

The main criteria for carrying out this task is to provide visual aids to the group, and to apply vividness criteria in presenting data. An implied criteria is to maintain equal participation in generating the reference modes.

POLICY CHOICES

Policy choices are the alternative courses of action which will either result in the desired reference mode or will alter an undesirable reference mode. All of the previous tasks will imply alternatives. Groups and individuals have a tendency to limit their thinking when they are discussing action alternatives to those that are thought "controllable" or feasible. As a result of this tendency, the model structure is unnecessarily constrained and it resembles the existing system which is responsible for the problem behavior in the first place. In order to encourage the generation of creative options, the main criteria is that the policy alternatives should not be evaluated as to feasibility of implementation.

BASIC MECHANISMS

The basic mechanisms refer to the causal relationships or interactions among variables which generate the system behavior that is of interest. Their definition requires a thorough review of all perspective components and their interrelationships so as to establish a more detailed causal framework in achieving the reference mode. Since the previous tasks have generated a number of perspectives with corresponding time frames, reference modes, assumptions and policy choices, the group will have to concern itself with a complex set of variables and the interrelationships which are in force. At this point, the challenge is to structure these components by combination and elimination in a non-arbitrary way while enhancing the group capability to integrate information.

Given the limitations of human judgment and information integration, the following criteria are proposed:

1. If unaided, individuals as well as groups suffer severe limitations when dealing with complex situations, a concept commonly referred to as "bounded rationality" (Simon, 1969). These limitations reflect themselves in arbitrary selections of perspectives and information which have been generated in the previous steps. To surpass these limitations, cognitive aids to structure the complexity should be employed.

2. When exploring the interactions between components, the group should search for base-rate information relevant to the causal relationships and present it visually along with concrete case examples.

3. In cases of disagreement concerning the validity or interpretation of the base-rate information, a structured debate should be organized to present the various assumptions and counter-assumptions.

The application of these criteria to SD modeling is presented in another paper presented at this conference where a combination of structural modeling procedures and a generic SD model are proposed as the cognitive aids.

EXPECTED OUTCOMES

The operationalization of these criteria for SD modeling applications will vary, but various measurements may be taken to generate information which is useful for understanding the cognitive strategies that are used during the problem definition and model structuring process. Three concepts which can be operationalized and implemented to evaluate the procedure are cognition, creativity and social interaction.

Cognition is defined as the mental operation involving active manipulation of information, including perception, learning, memory and thinking for purposes of problem solving (Mayer, 1983). Measures of the concept seek to determine if the procedure as applied promotes accuracy, efficiency and consistency in the acquisition and use of information. The benefit of using such measures is that judgments and inferences are expected to be more accurate due to the attention given to the quality of information and its interpretation. The specific uses of information such as base-rate data can be monitored and compared with a normative model of the judgment and inference process to determine the level of accuracy achieved. Furthermore, each participant's general understanding and knowledge of the systems and issues being modeled is expected to improve. One could perform a simple before and after test of each participant's knowledge of relevant information. And finally, individuals are expected to find the procedure relatively easy or painless when compared to the unstructured approach to complex problems such as those typically encountered in public and political meetings. Participants may simply be asked to compare these group sessions with others they have attended.

Creativity refers to the process and/or the product. The essential feature of the creative process is the grasping of previously unrelated and essential parts of a problem in a new pattern. As a result, a novel and appropriate product is created and the heuristic process that the group utilizes to achieve this elicits an aesthetic response from both the participants and the observers, such as surprise, satisfaction and stimulation (Amabile, 1983). Operationalizations of the concept should therefore attempt to measure both the number of solutions generated by the group and the originality of those solutions. In addition, participants can be queried to determine the level of satisfaction they experience from their involvement with the development of such original solutions. It is expected that use of the outlined criteria will result in greater numbers of solutions being generated. A simple count can be made at appropriate points in the process. It is also expected that the solutions will exhibit greater originality due to requirements of the procedural criteria. Either the participants themselves or a separate group of problem-solving experts can be asked for their opinions regarding the originality of solutions. It is also expected that the individuals will benefit from greater satisfaction or pleasure based on their involvement in producing such original work. The aesthetics of the procedure itself are thought significant and will most likely increase the satisfaction of those participating. The participants can then be queried at the end of the model structuring exercise to measure the levels of satisfaction achieved.

Social interaction is defined in terms of the level of participation achieved, the numbers of participants or size of the group, the diversity of that group in terms of knowledge, interests, and perhaps cognitive styles, and the clarification of values which occurs because of factors associated with groups and group process. The level of participation is expected to be high if care is taken to guarantee anonymity and promote individual contributions. In addition, by establishing a shared perspective, each individual is expected to feel at ease knowing that others also have the same concerns and are perhaps more receptive to ideas pertinent to overall group opinion. Individuals can be scored for the number of contributions made, whether they are ideas, opposing views, or conforming behaviors.

The number of participants is also expected to be greater when the above criteria are applied because of the gradual enlargement of the group when either expert knowledge or interest group responses are required. As the group searches for information, experts will be added for their specific knowledge. Others will be included because of the interests they may have in proposed solutions. Numbers of participants can easily be counted and differentiated into original members, new expert members and new interest members. This will also allow for a measure of participant diversity. The individuals can be scored for the specific information and problem-solving styles they bring to the group. And finally, participants are expected to experience a general clarification of values, whether consensus is reached or divergence and eventual polarization of opinion occurs. Again, a before and after test can be used to determine each individual's values and to measure whether clarification occurs.

In general, making these outcome measurements in the field will not provide a rigorous evaluation of a procedure used to satisfy the above criteria. However, a modeling procedure which keeps a running record of the evolving task structure, the information base and the relevant aspects of social interaction, and which evaluates these using the suggested outcome measures, will generate a valuable data base for gaining insight concerning human problem-solving.

CONCLUSIONS

When model structuring in SD is reviewed it is apparent that the major difficulty in modeling less structured problems lies in the problem identification stage. This stage consists of determining the perspective, the time horizon, the policy choices, the reference mode and the basic mechanisms. Unfortunately, the completion of each is left to the discretion of the model builder. The objective should be to successively narrow the scope of the problem to converge on a final representation in terms of a reference mode and the main causal mechanisms. The major shortcoming of this procedure is an arbitrary and premature closure in problem definition with possible judgmental biases in information processing and insufficient participation of the various stakeholders.

In order to avoid the above shortcoming it was necessary to examine the nature of human judgment and information processing, and of group dynamics. Elements of each which are capable of enhancing problem definition activities were identified and used to develop applicable criteria.

These criteria correspond to each of the problem definition tasks in SD. When identifying the perspective the main objective is to externalize and include the variety of viewpoints regarding the situation. In defining the time horizon, the sources of information required to operationalize these viewpoints are identified and the data requirements for future modeling stages become clear. Similarly, the reference modes corresponding to the perspectives are established with the help of appropriately presented base-rate information. The main theme in defining policy choices is to encourage the generation of creative options. Application of the criteria to these tasks implies the use of divergent processes rather than the convergent procedures typical of the problem identification stages of SD modeling. As a result, completion of the final task, i.e., the identification of the basic mechanisms, involves structuring the complex sets of values and information compiled in the previous stages. The expected benefits of these criteria in SD modeling are in enhancing the cognitive, creative and social interaction aspects of problem solving.

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