Model Conceptualization in Group Model Building: A Review of the Literature Exploring the Tension Between Representing Reality and Negotiating a Social Order

Aldo A. Zagonel
Doctoral student - University at Albany, SUNY
Rockefeller College of Public Affairs and Policy
11 Pheasant Ridge Dr. – Loudonville, NY 12211
Phones: (518) 439-4183 and 446-9651
E-mail address: zagonel@aol.com

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There is a growing practice of building system dynamics models directly with groups. This paper traces a genealogy of group model building (GMB) along two stream of thought. It focuses upon exploring the tension between modeling as a representation of reality, and modeling as a tool for negotiating a social order. The literature is organized into five clusters that roughly represent the members of a genealogy tree. A description of GMB is developed to fit an ideal type conceptual dichotomy. Findings are summarized in tables, mostly quoting directly from surveyed authors. The paper offers supporting evidence to the thesis that there are two intertwined threads in the group approach to system dynamics modeling. GMB interventions strive both to create a shared understanding of an interpersonal or inter-organizational problem, in the form of a "boundary-object" model, and to build a "micro-world" type model that is useful in terms of organizational redesign.

Key words: Group model building, system dynamics, decision conferencing, competing values approach, problem identification, problem definition, system conceptualization, micro-world, boundary-object.

Introduction[1]

Approaches to *systems thinking* (Richmond 1987/97, Morecroft and Sterman 1994, Richardson *et al.* 1994-A, Kim and Senge 1994), *strategic planning* (Eden 1989, Carper and Bresnick 1989, Quaddus *et al.* 1992, Bryson 1995), *decision analysis* (Adelman 1984, Buede and Bresnick 1992), *decision support* (DeSanctis and Gallupe 1987, Phillips 1988, Vennix *et al.* 1992/94), and *decision conferencing* (Weiss and Zwahlen 1982, Reagan *et al.* 1991, Schuman and Rohrbaugh 1991) are increasingly coming to rely upon the practice of building models directly with management teams and decision-making groups. The objectives of these researchers and practitioners are manifold, ranging from improving group decision-making processes to enhancing group, team and organizational effectiveness and productivity (Andersen *et al.* 1997).

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[1] I'd like to thank David Andersen, George Richardson and John Rohrbaugh for introducing me to the intricacies of system dynamics, decision conferencing and group model building, and for their continued support. The opportunity to work as a student, and hands-on apprentice, with these wise masters and generous friends has been of immeasurable value to me. To David my special thanks for suggesting that I structure my confusing thoughts as a dichotomy. Hopefully my research theme has become a little more tangible as a result of writing this paper.

The importance of involving the clients in the process of model building has been recognized early on in the field of system dynamics. Forrester (1961) stated that the power of system dynamics lies in the ability to use information obtained from the clients, and to portray more usefully its implications (p. 117). He also emphasized the relevance of the clients in terms of establishing model validity, as a measure of confidence in the model's correspondence to the clients' actual system (Chapter 13). Roberts (1978-B, 1978-C) made more explicit claims through a series of recommendations, such as: realize an opportunity important to the client, maximize in-house involvement as a means to secure implementation, and gear tests of validity to clients' assurance criteria, among other thoughts on the significance of client involvement.

A recent development in the field of system dynamics involves more active client engagement especially but not exclusively in the conceptual phase of model building, in the form of group meetings or conferences. This line of research and practice has been termed group model building (Richardson *et al.* 1992, Vennix *et al.* 1997). Richardson (1999) defines it as "the processes and techniques designed to handle the tangle of problems that arise in trying to involve a large number of people in model construction" (p. 375). Vennix (1996) characterizes it as a kind of group decision support for helping teams tackle strategic problems (p. xi). Gradually, a unified body of knowledge containing methodological guidelines to develop group model building procedures is flourishing (Richardson and Andersen 1995, Vennix 1996, Andersen and Richardson 1997). As they are experimented with, these procedures are also being extensively evaluated and tested (Rouwette *et al.* 1999, 2002).

While group model building is based essentially in the system dynamics model building method, deeply involving a client group in the process of model construction has required theoretical and applied input from other fields, such as sociology, social psychology, and small-group research (Vennix 1999, p. 379). In the applied-research in group model building that is being conducted in Albany, this influence has been filtrated and boosted in terms of a framework called decision conferencing (Rohrbaugh 2000).

While one could probably apply group model building to modeling any sort of dynamic problem, it seems that particular kinds of problems or situations "attract" the application of this approach. Group model building interventions will often address problems that involve multiple stakeholders that contribute with partial views of the system, but who are affected by the system as a whole (Huz *et al.* 1997, Rogers *et al.* 1997). They are also particularly useful in situations in which there is strong inter-personal disagreement in the client group, regarding the problem and/or regarding the policies that govern system behavior. Vennix (1999) refers to the latter as messy problems, i.e., "a situation in which opinions in a management team differ considerably" (p. 379).

Thus, this approach to system dynamics modeling, referred to as group model building, is a result of specific, and probably identifiable, idiosyncrasies. These are related both to the theoretical contributions from the several domains of knowledge that are shaping it (system dynamics, small group research, etc.), and to the nature of its application (messy problems, inter-organizational problems, etc.). If we were to think of group model building as an entity, we might choose to understand it in terms of its background (or genealogy) and nature (or personality). This is the intent of this literature review. To understand and describe group model building, both in terms of its ancestry and persona.

Tracing a genealogy of group model building

The genealogy of group model building will be traced from the point of view of the approach used by a research group working at the University at Albany. There are at least two schools of thought contributing to group model building practice in Albany, as illustrated in Figure 1.

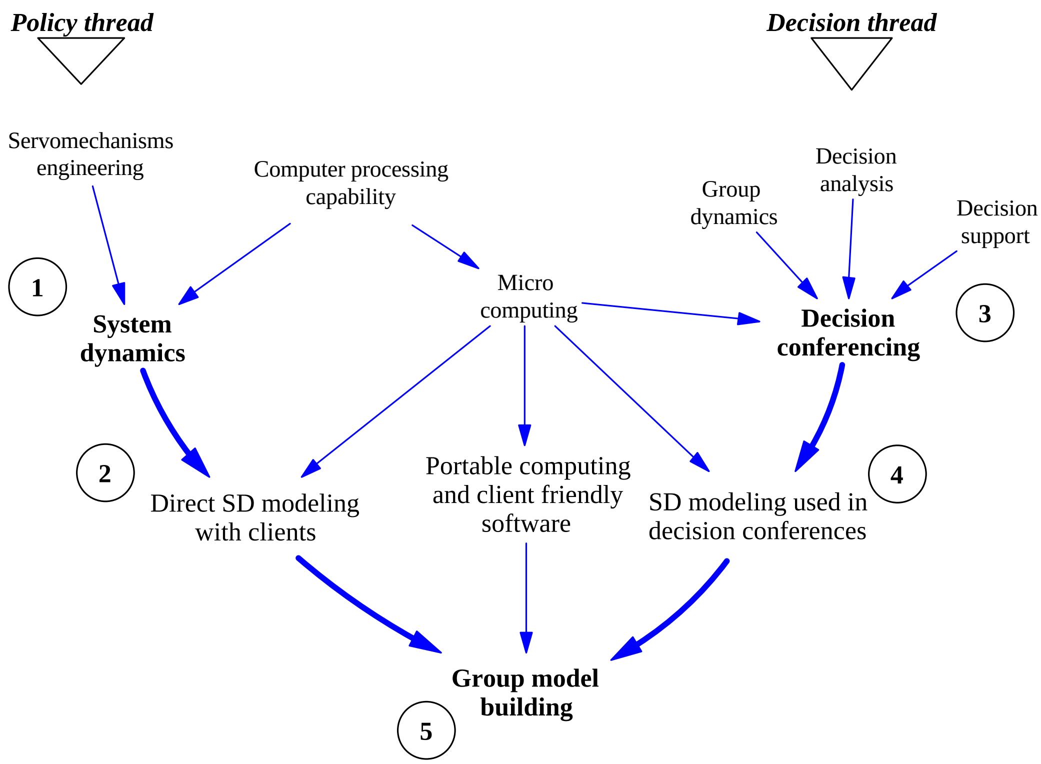

Figure 1. Tracing a genealogy of group model building.

System dynamics[2] is at the root of the *policy* stream. The system dynamics model building method can be described in phases that begin with a clear definition of the problem of interest, and end with a conclusive statement about this problem, containing policy recommendations aimed at its solution or mitigation (Richardson and Pugh 1981, pp. 15-17). This method is based upon an endogenous feedback view of system causes and effects. Solutions to the perceived problem are revealed through feedback thinking, the key expertise offered by system dynamicists (Forrester 1961, Sterman 1994).

[2] The Encyclopedia of Operations Research and Management Science contains an elaborate statement defining and explaining the system dynamics method, tracing its roots to servomechanisms engineering (Richardson 1996-A). Simply stated, Richardson claims that "system dynamics is a computer-aided approach to policy analysis and design" (p. 656).

The second stream, called the *decision* stream, is formed by a confluence of schools that gave shape to the decision conferencing framework. Those are group dynamics, decision analysis and decision support (Rohrbaugh 2000). People who conduct decision conferences consider themselves technique/process experts, and they focus upon the appropriate techniques and the best processes used to arrive at decisions (Reagan and Rohrbaugh 1990, Reagan *et al.* 1991, Nunamaker *et al.* 1991). They help structure problem solving while focusing upon facilitation and elicitation strategies and techniques (Phillips and Phillips 1983, Moore and Feldt 1993, Griffith *et al.* 1998).

A purposive sample of the literature was chosen to represent each of the five clusters depicted in Figure 1:

1. Classic system dynamics
2. Direct system dynamics modeling with clients
3. Decision conferencing
4. System dynamics modeling used in decision conferences
5. Group model building

These key references are listed in the Appendix, by cluster, in chronological order. These references not only help us understand the origins of group model building, but they also serve as the source of information for revealing and understanding its main features and characteristics.

<u>Revealing the characteristics of group model building</u>

The first major characteristic of group model building is its diversity in objectives and expectations, resulting most likely from the confluence of the diverse influences giving shape to it (system dynamics, small-group dynamics, decision support, etc.). A superficial examination of its genealogy alone will reveal a tension between policy *versus* decision, and between content *versus* process. To some extent these tensions overlap.

The decision conferencing influence emphasizes a decision to be made, and focuses upon the processes that lead up to this decision. Decision or process oriented objectives in group model building may be stated as accelerating a management team's work (Vennix *et al.* 1992/94), problem structuring and classification schemes (Eden *et al.* 1983; Vennix *et al.* 1988, 1990), generating commitment to a decision (Rohrbaugh 1992, Vennix *et al.* 1993), creating a shared vision and promoting alignment (Huz *et al.* 1997), and creating agreement or building consensus about a policy or decision (Winch 1993, Vennix 1994)

Alternatively, policy or content oriented objectives may be stated as improving shared understanding regarding the system or problem at hand (Eden and Ackermann 1992, Bryson and Finn 1995), system improvement, and system process and outcome change (Richmond 1987/97, Cavaleri and Sterman 1997). These involve changing the mental models of individuals in the group or organization, guided by insights produced using the modeling tools and methods (Richardson and Senge 1989).

Ideally, as Eden (1990) appropriately points out, astute analysis (content) and skillful facilitation (process) should be combined: "within the context of group decision support it may be suggested that the two skills can become integrally tied together so that they are fully interdependent" (p. 49). In the context of group model building, this may be stated as promoting organizational learning (Senge 1990, Vennix and Scheper 1990, Morecroft and Sterman 1994) and organizational change (Akkermans *et al.* 1993, McCartt and Rohrbaugh 1995, Vennix *et al.* 1996), or promoting collaboration and cooperation amongst interdependent stakeholders (Kraemer and King 1988).

The combination of adequate analytical tools that appropriately address the content of a problem, with careful facilitation and elicitation procedures, resulting in an effective intervention, is at the heart of the decision conferencing framework. Nevertheless, it involves a great deal of tension reflected in pursuing competing values (Reagan and Rohrbaugh 1990). However, Forrester (1987-B) warns that emphasis on *decision*-making can obscure attention that ought to be placed in *policy*-making:

> A number of "obvious truths" seem to have been accepted in varying degrees as the philosophical guidelines for much of the search for a scientific foundation underlying management and economics. All of the following appear to be given at least some credence, and all seem to me to be misleading: … That emphasis in models should be on decision making. The sharp distinction between policy and decision has been obscured. Too much attention has been concentrated on the individual decisions and not enough on the policy that governs how the decisions are made. Models … should be directed toward policy. In other words, what are the rules by which information sources are converted into a continuous flow of decisions? (p. 159).

Much can be learned from contrasting these two roots of group model building. But, for the purpose of this paper, I've chosen to probe the existing tensions in group model building in terms of a dichotomy between building models to *represent a reality* as opposed to building models to *construct a socially negotiated order*. Whereas the genealogy of group model building reveals much insight about its origins and contributing traces, I believe contrasting these two views of model building will be even more revealing in terms of its present characterization.

A dichotomous view of group model building

My thesis on group model building is that it is a *multithread* approach to team learning, decision making, and policy change. While there is a host of technologies and techniques that give shape to the group model building portfolio, analyzing them separately does not necessarily yield the best understanding of the method. Instead, I propose examining it from the point of view of a simple dichotomy. On the one hand, the model built by the group is perceived as a "micro-world"[3] representation of reality. On the other, it is understood to be a "boundary-object"[3] to arrive at a negotiated view of the group's social order. Table 1 distinguishes conceptually these two proposed views of the model.

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[3] I use these terms metaphorically, without much concern regarding their meanings as social-scientific concepts.

Table 1. “Definition” of the dichotomous view of models in group model building.

Models as “micro-worlds”:	Models as “boundary-objects”:
Problems are preexistent in the system we’re modeling. We do our best work to get the important elements of the problem and the facts right, to create a realistic representation of this policy system, and to accurately address the content of the issue we’re modeling. We strive to find the “correct” solution to the problem. We’re focused upon the results and outcomes of this group model building intervention, in terms of the answers it will provide to the questions we have about our reality. Therefore, our group process needs to be effective at getting at the answers we need. We need clarity in both purpose and problem in order to proceed efficiently.	Problems emerge from debate and discussion. We do our best work to come upon a shared understanding regarding what we think our problems are, and how we might best tackle them. We strive to understand our complementary and sometimes competing views, to build a joined picture that we can understand and share. We’re concerned with reconciling our different views and opinions so that we may proceed toward a better solution to our problem. The process we use to “negotiate” this model is as important, if not more important, than the accuracy of the model as a representation of our reality. Therefore, our group process needs to be open and fair.

While this dichotomy represents an ideal type of sorts, it is useful, however, to examine the higher purposes for which models are used in group model building. Furthermore, it helps us to understand how the multiple technologies and techniques are combined, and more or less emphasized, in the process of building models with groups. This dichotomy artificially separates the pursuit of truth from consensus building. It servers to highlight many of the tensions found in group model building theory and practice. One of the key objectives of this research is to understand how these two threads are coming together in the form of group model building, and the implication thereof. I argue that good group model building involves understanding and balancing these two views. Ideally, group model building interventions will result in consensual learning, most commonly referred to as team learning. The alternatives are mistaken consensus, or groupthink[4], and insightful models that have little or no impact in the lives of people.

In this paper, I will survey the literature identified in the genealogy of group model building, focusing upon two phases of the system dynamics model building method: problem identification and definition, and model conceptualization. I will map this literature into the proposed dichotomy, and I will argue that there is a close fit. Prior to that, I will introduce the competing values approach framework, distinguish the phases of model building, and provide an illustration of the dichotomy.

[4] “Where members of a group mutually reinforce their current beliefs, suppress dissent, and seal themselves off from those with different views or possible disconfirming evidence (Janis 1982)” (Sterman 2000, p. 33).

The competing values approach to group decision process effectiveness

There exists a theoretical foundation related to the proposed dichotomous view of models in group model building. It can be extracted from the competing values approach to group decision process effectiveness, found in the decision conferencing literature (Quinn and Rohrbaugh 1983, Quinn *et al.* 1985, McCartt and Rohrbaugh 1989, Rohrbaugh 1989, Rohrbaugh and Eden 1990, Reagan and Rohrbaugh 1990, Rohrbaugh 1992, McCartt and Rohrbaugh 1995).

Although the proposed dichotomy was conceived independently, and *not* derived from this existing work, the process of reviewing the literature denounced its pertinence to the dichotomy between the "micro-world" and "boundary-object" views of group model building. Furthermore, I found a close parallel to the dichotomy in one specific article (Quinn *et al.* 1985). This section will provide a short review of the theoretical and empirical basis of the competing values approach framework, and refer to other similar frameworks found in the organization behavior and theory literature. It will also illustrate the parallel between the dichotomy that I'm creating, and the one discussed in Quinn *et al.* (1985). Finally, I'll briefly comment on the usefulness of this framework in terms of evaluating the effectiveness of decision conferences, as well as group model building interventions.

THE COMPETING VALUES APPROACH FRAMEWORK. The competing values approach (CVA) is a theoretical framework to organizational analysis that has been empirically uncovered, and confirmed, through the factor extraction statistical method of analysis (McCartt and Rohrbaugh 1989, p. 246). The theory proposed that there are four models of organizational analysis:

- an *open systems model* focuses on flexibility and readiness as the means by which resource acquisition and growth can be increased as primary organizational objectives;
- a *rational goal model* focuses on planning and setting objectives as the means by which productivity and efficiency can be improved …;
- an *internal process model* focuses on information management and coordination as the means by which stability and equilibrium can be developed …;
- a *human relations model* focuses on cohesion and morale as the means by which the value of human resources can be made greater…. (p. 246) [Emphasis added, order altered]

When this theoretical framework was applied to the process of group decision making, factor analysis revealed, empirically, four corresponding perspectives concerning the effectiveness of group decision processes. Figure 2, copied from McCartt and Rohrbaugh (1995, p.574), contains a synthesis of the results. While the theory drew a parallel with Parson's (1959) four functional prerequisites of any system of action, the empirical results mirrored Taggart and Robey's (1981) four dominant decision-making styles (McCartt and Rohrbaugh 1989, pp. 246-247). Table 2 provides a contrast between the labels given to the four quadrants in each of these frameworks.

Figure 2. The competing values approach to group decision process effectiveness
(Copied from McCartt and Rohrbaugh 1995, p. 574)

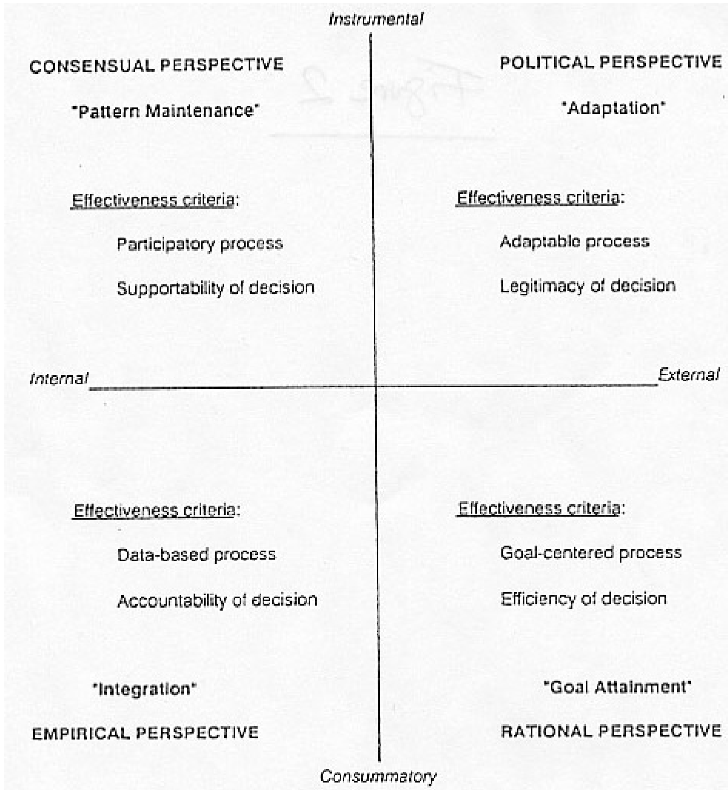

Table 2. The four quadrants of competing values contrasted across frameworks
(Derived from McCartt and Rohrbaugh 1989, pp. 246-247)

Empirically derided perspectives on effectiveness of decision making processes:	Competing values approach (CVA): (Theoretical framework of models of organizational analysis)	Parson's (1959) theory of functional prerequisites of any system of action:	Taggart and Robey's (1981) decision-making styles:
Political perspective Factor 1: Realism and resources	Open systems model	Adaptive function	Insightful style
Rational perspective Factor 2: Subjective rationality	Rational goal model	Goal attainment function	Logical style
Empirical perspective Factor 3: Information utilization	Internal process model	Integrative function	Matter of fact style
Consensual perspective Factor 4: Feelings and social compromise	Human relations model	Pattern maintenance function (tension management)	Sympathetic style

It is important to note that the factor extraction statistical method of analysis used by Milter (1986) and Rohrbaugh (1987), described in McCartt and Rohrbaugh (1989) revealed, more precisely, three dimensions (not two), resulting in eight (not four) distinct performance criteria by which to judge effectiveness in group decision processes. The last dimension is characterized by a distinction between ends *versus* means; i.e. the nature of the process *versus* the ends achieved (p. 247). Therefore, as depicted in Figure 2, two criteria of effectiveness are associated with each quadrant. In terms of *ends* achieved: 1) legitimacy of the decision, 2) efficiency of the decision, 3) accountability of the decision, and 4) supportability of the decision. In terms of *means-to-an-end*: 1) adaptable process, 2) goal-centered process, 3) data-based process, and 4) participatory process.

TWO APPROACHES TO DECISION MAKING. Quinn *et al.* (1985) proposed a *new* approach to organizational decision making, called automated decision conferencing (ADC), later to be referred as, simply, decision conferencing. They argued that this approach allowed executives "to integrate quantitative analysis and subjective intuition" (p. 49). They proposed this approach as an integrative alternative to more traditional approaches to decision making that focused upon only partial needs of decision makers:

> [W]e establish a framework that clarifies the value differences between the two most general approaches to decision making: the "hard" management science or operations research view and the "soft" group process or organization development view. We will then show how ADC integrates and unifies the values reflected by these very distinct approaches. (p. 49)

In essence, in their article, Quinn *et al.* use the CVA framework to characterize a dichotomy between management science and organization development. Figure 3, copied from p. 51, contains an illustration of how these two approaches would occupy the four-quadrant space described above. There is an obvious parallel between the dichotomy illustrated in this figure, and the one that I describe in this paper. I recognize this fact. I also take advantage of it, by drawing upon this literature throughout the paper, as a source of insight to the existing tensions between using a model to represent a reality, and as an instrument to negotiating a social order.

For instance, the authors indicate that the criteria for effectiveness in any given quadrant "tend to complement somewhat the criteria in neighboring quadrants" but "stand in sharp contrast to criteria in the opposite quadrant" (p. 50). They also argue that there are several reasons why some quadrants may be more or less emphasized than others: 1) disciplinary and methodological biases, 2) personal values, and 3) situational demands (p. 51). With respect to the latter, they hypothesize:

> When time pressures are high, little emphasis will be placed on the consensual and empirical approaches. Instead, emphasis will shift to [political and rational] criteria… When time horizons are long, the opposite shift may occur. When uncertainty is high, tightly regulated, analytical methods are less likely to be used… When certainty increases, the emphasis will shift toward more empirical and rational approaches. (p. 51)

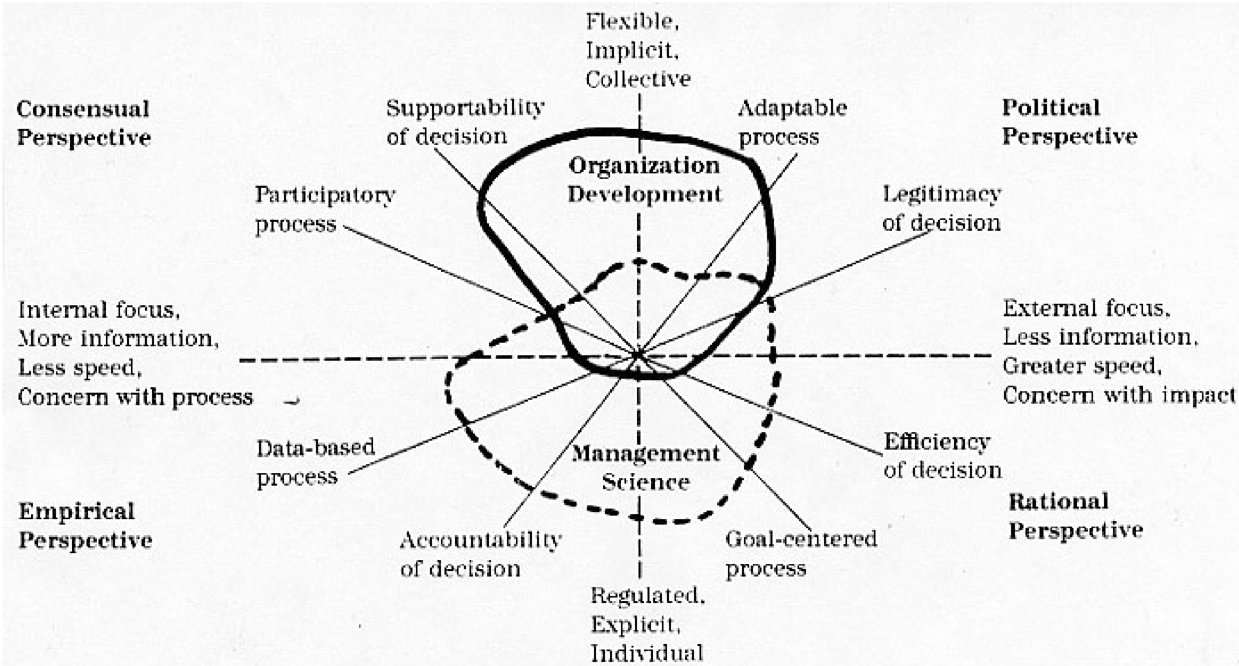

Figure 3. Two approaches to decision making
(Copied from Quinn *et al.* 1985, p. 51)

Similarly to these authors, this paper describes a vision for group model building that also integrates these competing values. The contrast I describe is between the "hard" approach to model building represented by the "micro-world" view, and the "soft" approach represented by the "boundary-object" view.

The CVA framework has been extensively used in terms of evaluating the effectiveness of decision conferences (Reagan and Rohrbaugh 1990, Rohrbaugh 1992, McCartt and Rohrbaugh 1995). The sort of evaluation proposed is based upon assessing the *processes*, not the *outcomes*, of interventions (Rohrbaugh 1989). It has also been used to "understand the mix of method, consultant style, and client setting that in combination define [the] 'ways of working'" between consultants and clients (Rohrbaugh and Eden 1990, p. 40). It is important to consider this knowledge base, when attempting to improve the effectiveness of group model building.

The phases of the system dynamics modeling method

Several authors have found useful to describe the system dynamics method in terms of its phases (see Table 3). Andersen and Richardson (1979/80) proposed a seven-phase iterative[5] process consisting of both conceptual and technical phases. This framework was also adopted in Richardson and Pugh (1981), and Roberts *et al.* (1983). Except for some small variations, these phases can be specified as: 1) problem definition, 2) system conceptualization, 3) model

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[5] Randers (1980-B) afirms that "no amount of prior lessons will transform modeling into a sequential execution of a set of activities requiring no repetition" (p. 130). See also Homer (1996).

formulation, 4) model behavior, 5) model evaluation, 6) policy analysis, and 7) model use or implementation.[6]

Table 3. Phases, stages or steps of the system dynamics model building method.

<table>
<tr><th>Andersen and Richardson (1979/80, p. 93)</th><th>Richardson and Pugh (1981, p. 16)</th><th>Roberts et al. (1983, p. 8)</th><th>Sterman (2000, p. 87)</th></tr>
<tr><td>Problem recognition</td><td>Problem identification and definition</td><td>Problem definition</td><td>Problem articulation (boundary selection)</td></tr>
<tr><td>System conceptualization</td><td>System conceptualization</td><td>System conceptualization</td><td>Dynamic hypothesis</td></tr>
<tr><td>Model representation</td><td>Model formulation</td><td>Model representation</td><td rowspan="2">Formulation</td></tr>
<tr><td>Model behavior</td><td>Analysis of model behavior</td><td>Model behavior</td></tr>
<tr><td>Model evaluation</td><td>Model evaluation</td><td>Model evaluation</td><td>Testing</td></tr>
<tr><td>Policy analysis</td><td>Policy analysis</td><td rowspan="2">Policy analysis and model use</td><td>Policy formulation (design) and evaluation</td></tr>
<tr><td>Model use</td><td>Model use or implementation</td><td>Decisions (organizational experiments)</td></tr>
</table>

Sterman (2000) uses a slightly different framework, based upon five phases only: 1) problem articulation, 2) dynamic hypothesis, 3) formulation, 4) testing, and 5) policy formulation and evaluation (p. 87). Except for the added emphasis in developing a dynamic hypothesis, as opposed to system conceptualization in general, Sterman's approach simply collapses model formulation and model behavior into the formulation phase. Implicit in Sterman's framework is a sixth phase called "decisions", where the results of the modeling effort are to be implemented (p. 88).

In this paper, I will distinguish the phases of the system dynamics modeling method as follows:

1. Problem identification and definition
2. Model conceptualization
3. Model formulation and simulation
4. Model testing and evaluation

[6] Andersen and Richardson (1980), p. 93; Richardson and Pugh (1981), p. 16; Roberts *et al.* (1983), p. 8.

5. Model based problem analysis and policy experimentation
6. Understanding and discernment
7. Policy implementation (action) and outcomes

This framework also collapses model formulation and model behavior into a single phase. However, it makes explicit the transition from the modeling work to model use or implementation by including a new phase called "understanding and discernment". As a matter of personal choice, these are the seven phases that will be used to hold the discussion regarding a dichotomous view of models in group model building, beginning with the inspection of 1) the problem identification and definition phase, in the next section, and 2) the model conceptualization phase, in the second half of this paper. Figure 4 illustrates this alternative view of the system dynamics model building method.

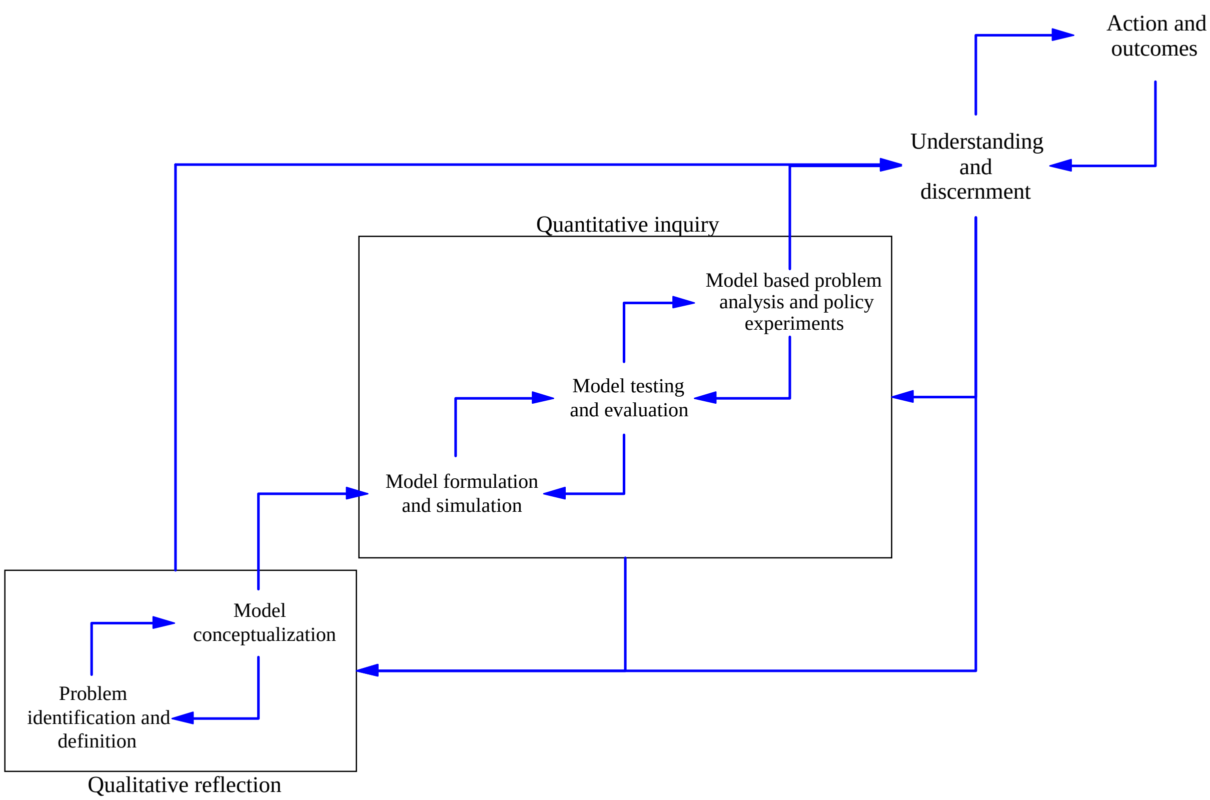

Figure 4: Steps of the system dynamics model building method.

This figure depicts the phases of the method as a sequence of iterative steps, as in climbing up and down a ladder. The first two steps have to do with a qualitative reflection involving problem definition and model conceptualization. The next three steps relate to a quantitative inquiry based upon model formulation and simulation, model testing and evaluation, and model based problem analysis and policy experimentation.[7] The iteration happens both

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[7] Randers (1980-B) distinguishes these two clusters (qualitative reflection *v.* quantitative inquiry) in terms of model conceptualization *v.* formulation (p. 130): "The goal of the conceptualization stage is to arrive at a rough conceptual

within each cluster of steps, and across clusters, as desired or needed. At any point in the process, there exists some degree of understanding and discernment regarding the problem and the system under study.

It is assumed that as one climbs toward the higher steps, from qualitative analysis to quantitative inquiry, and from formulation to testing, to model based analysis, the level of understanding and discernment improves and gains accuracy.[8] At some point in this process, if the model building effort is to be successful, the insights generated will result in decisions and actions in the form of new policy implementation. Those, in turn, will lead to new outcomes.

A detailed list and discussion of the specific ingredients of each phase (or step) involved in the system dynamics process can be found in several sources.[9] A selected set of these ingredients will be addressed in the discussion of the dichotomy to follow. Table 4 is a creative illustration of the dichotomy as I expect it to unfold across all phases of the model building method.

1. The dichotomy in problem identification and definition

The first step to building a system dynamics model is problem identification and definition. In this phase of the model building process, several important elements of the model building effort need to be addressed. Some of these are: a) identifying the problem/issue to be modeled; b) establishing the purpose of the modeling effort; c) specifying the audience interested in the results of the work (sometimes a client); d) revealing the time-horizon involved in the unfolding of the problem, and in the quest for a solution to it; e) identifying the key variables; and f) eliciting or otherwise obtaining reference modes for the problem variables (Richardson and Pugh 1981, Chapter 2; Randers 1980-B; Sterman 2000, pp. 89-94). Key to understanding the dichotomous view of models in group model building are the issues related to establishing the focus of the intervention: identifying the problem to be modeled, the purpose of the modeling effort, and the audience (or interested or otherwise affected parties).

Tables 5a, 5b and 5c, found attached in the Appendix, lay out the organization of this discussion, and contain an epitome of my findings while mapping the literature into the dichotomy, mostly quoting directly from the authors surveyed. The left-hand column portrays the micro-world view, inherited from the system dynamics tradition. The right-hand column portrays the boundary-object view, extracted from the group model building literature, and from the literature in system dynamics modeling used in decision conferencing. The elements in the left-hand column can also be found in the group model building literature, but I chose to quote from the original authors. Thus, both sides of the dichotomy can be found in the group model building literature.

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model capable of addressing a relevant problem. The formulation stage should embrace two processes: the test of the dynamic hypothesis … and model improvement…" (pp. 130-131).

[8] The extent to which qualitative analysis alone can lead to understanding and discernment or, alternatively stated, the extent to which quantitative inquiry is essential, is a highly controversial topic in system dynamics. The arguments and counter-arguments in this ongoing discussion are most recently summarized in Coyle (2000, 2001) and Homer and Oliva (2001).

[9] Richardson and Pugh (1981), Chapters 2, 4, 5 and 6; Roberts *et al.* (1983), pp. 8-10; Sterman (2000), pp. 85-104.

Table 4. A creative illustration of the dichotomous view of models in group model building.

Question: How do intervenors and participants view the model they are building?

Steps of the SD method:	Model as "micro-worlds":	Model as "boundary-objects":
1. Problem identification and definition	▪ Monolithic client ▪ Preexisting problem ▪ The modeling purpose is to identify and solve a problem	▪ Multiple constituencies ▪ Socially constructed problems ▪ Multiple purposes, starting with negotiating a shared view
2. Model conceptualization	▪ Getting at the facts ▪ Envisioning the causal feedback structures capable of reproducing the problematic behavior	▪ Agreeing upon "reality" ▪ Model is a synthesis of the group's negotiated view of "reality" (issues of scope and level of aggregation)
3. Model formulation and simulation	▪ Build a quantifiable model and test the dynamic hypothesis ▪ Modeler's ownership of the model	▪ Should we even bother building a quantifiable model? ▪ Group's ownership of the model should not be threatened
4. Model testing and evaluation	▪ Organized approach to model testing and evaluation ▪ Modeler is free to review and adjust conceptualization and formulation	▪ Group judges model for structural and behavioral correspondence, mostly in terms of face-validity ▪ Significant changes in model conceptualization and formulation need to be checked with the group
5. Model based problem analysis and policy experimentation	▪ Structural analysis of the problem ▪ Experimentation with new causal structure and/or decision rules	▪ Strategic analysis of interrelated problems ▪ Experimentation with alternative strategies and scenarios
6. Understanding and discernment	▪ What's causing the problem? ▪ How can we fix it?	▪ Do we agree on the problem? Do we share a view of the system? ▪ Are we ready to make a decision
7. Policy implementation (action) and outcomes	▪ Structural change ▪ Change resulting from "new" understanding regarding relationship between structure and behavior	▪ Changes in goals, objectives and strategy ▪ Change resulting from agreements in goals, objectives and strategies

Tables 5a, 5b, and 5c will be discussed in the following order. First, I will address the micro-world view (left-hand column). I extract two related underlying assumptions from it. First, that while problems can be complex, they are still "preexistent" and can be clearly specified. Second, we know or we can find out sufficient information about the problem to model it. Sterman (2000) argues that while natural and human systems have high levels of dynamic complexity (p. 21), the most complex behaviors normally arise from the interactions among the components of the system, and not from the complexity of the components themselves (p. 12). Forrester (1987-A) proposes that the components of the system (causal structure and decision policies) can be reliably extracted from the mental database of the people who experience the system, and from other available information. Moreover, he states that, from the mental database, consensus usually emerges that is useful and sufficiently correct (p. 144).

The field of system dynamics contains countless examples of complex issues that have been successfully modeled, many of which addressing complexity in social systems (Forrester 1961, Part III; Forrester 1969, 1971-B; Roberts 1978-A; Meadows *et al.* 1992; Richardson 1996-B; Ford 1997; Sterman 2000, Chapter 2; to cite but a few).[10] But, can it be assumed that these two assumptions are always true? For example, Richardson and Senge (1989) contrast two independent system dynamics studies in which the rising costs of liability insurance are modeled. In one case, while a sophisticated model was built to assess the effectiveness of alternative policy options, the problematic behavior driving the system could not be endogenously modeled. Because, "at the aggregate level of regulatory politics, no one [was] confident they [knew] why settlement awards [were] growing at 20-to-25 percent per year" (p. 16).

The boundary-object view will be discussed second. In it I'll survey less clear and specific problems and realities, and I'll report on how the above-mentioned elements of the model building process (problem, purpose, and client) might be interpreted somewhat differently in the modeling process.

View of models as "micro-worlds"

<u>The problem</u>

Classic system dynamics offers clear guidelines as to establishing the focus of a model building project. Forrester (1961) argues that a model should be designed to answer a specific, tangible, and meaningful question, or set of questions (p. 449). This implies that questions should be precisely and explicitly stated, and they should relate to real and actual phenomena. It is impractical (and impossible) to model a system (Sterman 2000, pp.89-90). In order to build a model, one must draw a boundary, deciding what are important elements to include in the analysis, and leaving out non-essential elements in the system (Sterman 2000, pp. 79-80). The choice of the problem defines this boundary (Richardson and Pugh 1981, pp. 42-43). For this reason, system dynamicists emphasize that models should be developed to address a particular

[10] System dynamics models are not without criticism. Among the most controversial work are Forrester's *Urban Dynamics* (1969) and *World Dynamics* (1971-B). For example, see Brewer and Hall (1973) and Nordhaus (1973). Criticism of *World Dynamics* has been rebutted in Forrester *et al.* (1974).

problem, as opposed to modeling the system (Richardson and Pugh 1981, p. 18; Roberts *et al.* 1983, p. 167; Sterman 2000, pp. 79 and 89-90).

A meaningful system dynamics problem is a relevant and dynamically complex problem. Sterman (2000) states that worthy problems are those in which the modeling work can have lasting benefits (p. 84). Ultimately, the client and/or the audience should perceive the problem as relevant (Stenberg 1980, p. 308; Sterman 2000, p. 85). Reagan *et al.* (1991) propose that the primary strength of system dynamics models is fostering understanding of complicated interrelationships and feedback-rich systems that make policy-problems complex (p. 62). System dynamics applies to problems that are dynamic and arise in feedback systems (Richardson and Pugh 1981, p. 19).

<u>The purpose</u>

Next to defining the problem, defining the purpose of the modeling effort is the most critical part of the undertaking. Forrester (1961) argues that the seasoned modeler knows that a systems study must be for a purpose if it is to be productive, pointing out that "the beginner tends to forge ahead into detailed construction of a model before its purpose has been adequately defined" (p. 449). Richardson and Pugh (1981) add, "a model without a purpose is like a ship without a sail" (p. 38). Classic system dynamics tends to favor understanding of key dynamics, for the goal of improved system performance, as the fundamental purpose of building models:

> The goal of a modeling effort is to improve understandings of the relationships between feedback structure and dynamic behavior of a system, so that policies for improving problematic behavior may be developed. (Richardson and Pugh 1981, p. 38)

The Claims Learning Lab described in Richardson and Senge (1989) serves as a good example of a model built for the purpose of fostering understanding of the key dynamics in insurance claims operations, particularly the dynamics pertaining to rising insurance costs.

Thus, Sterman (2000) defines system dynamics as a method to enhance learning in complex systems (p. 4). With understanding comes the desire to "fix" the problem:

> The goal is to improve performance of the system… The real value of the process comes when models are used to support organizational redesign… "The goal should be to find management policies and organizational structures that lead to greater success" (Forrester 1961, p. 449). (Sterman 2000, pp. 80 and 84)

In general, classic system dynamics has placed its emphasis, in terms of modeling purpose, in the goal of policy analysis and improvement, as found in, for example, Richardson and Pugh (1981). In this tradition, the purpose is normatively clear: to identify and solve a problem.

The client/audience

The last element providing the focus of a model building effort is the client or audience interested in the work. Classic system dynamics highlights three critical aspects related to client involvement in specific and to the audience in general. If the work is to be done for a client, to be effective the modeling process should be focused on the clients' needs (Sterman 2000, p. 85). Roberts (1978-B) recommends trying to solve a real problem that presents an opportunity perceived as important to the clients (pp. 78-79). If it is simply a research effort, then the audience of interest for the study must replace the client in terms of defining the purpose of the effort (Richardson and Pugh 1981, pp. 45 and 50). So, first and foremost, the clients/audience are essential in defining the purpose of the modeling effort, and in identifying the problem of interest.

Second, the clients are also a very important source of information in the modeling effort. They are the first source for both qualitative and quantitative information pertaining to the problem. They enrich the empirical basis of the analysis, and open up channels for the exchange of insights (Stenberg 1980, pp. 299 and 303). In the study of policy options for the Scandinavian forestry and forest industry, in the absence of a clearly defined client, Stenberg (1980) assembled a "reference group" as "a kind of mini-universe of the part of the real world under study" (p. 303). He also conducted additional empirical research drawing upon decision makers and outside researchers, as well as historical records and statistics, to arrive at a "richer and more accurate picture of those aspects of the real world that contribute to the dynamic behavior of the … model" (pp. 309-310).

Forrester (1987-A, 1992/94) identifies three sources of information for building system dynamics models: the mental, the written and the numerical databases. He argues that the written and numerical databases contain progressively less information for building a model, particularly about causal structure and decision policies (Forrester 1994, p. 72). He suggests that the dominant significance of information from the mental database is not sufficiently appreciated in the social sciences (Forrester 1987-A, p. 143). He concludes that if the mental database is so important in the understanding of social systems, then system dynamics models should draw primarily upon the mental database to reflect knowledge of organizational policies and system structure (Forrester 1994, p. 73).

A third reason why the clients are perceived as important actors in the modeling effort has to do with the implementation of modeling results. Implementation was an implicit concern in *Industrial Dynamics* (Forrester 1961), but Roberts (1978-B/C) made it explicit. He summarized the importance of active client involvement not only in terms of ensuring interest in the modeling work, and adequacy and accuracy of model formulation with respect to reality. But also in terms of providing the basis for implementation of the recommended policy changes derived from the modeling effort (1978-C, p. 156).

The dynamic hypothesis

System dynamicists often synthesize problem definition in the form of a dynamic hypothesis[11] (Stenberg 1980, pp. 307-308; Richardson and Pugh 1981, pp. 55 and 63; Sterman 2000, pp. 94-102). The dynamic hypothesis in a system dynamics study is a statement of the feedback structures in a system that are hypothesized to generate or contribute to the problem behavior (Richardson and Pugh 1981, pp. 55 and 63), as it is depicted in the reference modes (Stenberg 1980, p. 300). According to Randers (1980-B), the belief that the basic feedback structure can actually reproduce the reference modes remains an assumption until the model is formulated and simulated, and the output of the simulation proves the dynamic hypothesis to be correct –that is the actual behavior of the model resembles the reference modes (p. 131 and 134).

Sterman (2000) feels so strongly about the importance of the dynamic hypothesis concept that he decided to give this label to the conceptualization phase of the model building process (pp. 86-87):

> Once the problem has been identified and characterized over an appropriate time horizon, modelers must begin to develop a theory, called a *dynamic hypothesis*, to account for the problematic behavior… A dynamic hypothesis is a working theory of how the problem arose… Much of the remainder of the modeling process helps you to test the dynamic hypothesis… (pp. 94-95)

Richardson and Pugh (1981) add that while a dynamic hypothesis should be sketched early on in the modeling process, a well-focused, consistent and clear statement may not be possible until the model is formulated, simulated and evaluated extensively (pp. 56 and 63).

Stenberg (1980) reported spending as much as six months exploring problem definition prior to engaging in a particular model building effort. In retrospect, he found it to be a wise decision because it gave the rest of the project the necessary direction. He warns: "The model builder much too easily loses sight of the objectives of his work, and begins to develop a general purpose model that aspires to answer all questions but in the end yields disappointingly few insights" (p. 300).

View of models as "boundary-objects"

The analysis of complex problems can be difficult because critical information is lacking or because decision-makers lack the ability to effectively integrate and utilize the information that is available (Reagan *et al.* 1991, p. 53). For this reason, Simon (1957) proposed that decision-makers make bounded rather than optimal decisions. This is where system dynamics can be useful, by helping guide the selection, and by efficiently and effectively integrating and

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[11] The earliest citation I found to the concept of a dynamic hypothesis was in Stenberg (1980), p. 300/312, endnote number 3, referring to J. Randers' Ph.D. dissertation, p. 54: "Conceptualizing Dynamic Models of Social Systems: Lessons from a Study of Social Change," Alfred P. Sloan School of Management, MIT (September 1973), Cambridge, Massachusetts.

processing information that is interrelated in complex ways.[12] However, some would argue that *problems are interrelated*, and that there is room for ambiguity in problem selection and analysis (Reagan *et al.* 1991, p. 52).[13]

Stakeholders and multiple constituencies

The primary source for ambiguity lies in the fact that much too often multiple constituencies use multiple criteria, and multiple resources and constraints when thinking about and addressing complex problems. Thus, problem definition is perception-dependent and value-laden. Consequently, different people define and give shape to problems differently. This adds an additional layer of complexity to already complex situations (Vennix 1996, p. 1). When dealing not with one client, and not with a very specific and tangible issue, problem definition and policy analysis will most likely have to emerge from some sort of discussion. For example, Reagan *et al.* (1991) report using decision conferencing, based upon multiple technologies,[14] to help a client assess policy changes and their utility to various stakeholders.

In the forest study conducted by Stenberg (1980), at the start of the intervention the research team had a list of emerging problems that were interrelated. In deciding which problem to focus upon:

> They discussed in meetings with the reference groups what might become the most important problems… and how those problems could be dealt with. The team had to sort out temporary changes from persistent trends, attempt to explain the forces behind the trends, and then hypothesize about what kind of future would emerge… they would present theories and receive criticism or support. (p. 300)

We can clearly see how in these two cases, the problem and the analysis emerged and/or were given shape through discussion. The discussion not only involved the clients and/or stakeholders, but also the research team and its facilitator(s), who can be conceivably very influential in the whole process. Had the participants been different, would these groups have traveled the same paths, and arrived at similar conclusions? How robust were these processes in terms of resulting in the same outcomes? Could minor changes in these interventions, such as the use of an alternative facilitator, for example, have produced significantly different results and findings?

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[12] This paragraph should be revisited to avoid referring to Reagan *et al.* when should really be quoting from Simon directly, and to do a better job in specifying Simon's contribution to the SD paradigm, extracting quotes from classic system dynamics texts referring to Simon's work (for example, Sterman's link between bounded rationality and misperceptions of feedback).

[13] As argued in Eden *et al.* (1983), among others.

[14] In this particular case, a system dynamics model was combined with both a multi-attribute utility (MAU) model and a process designed to uncover and challenge the key assumptions on which policies and strategies rested (SAST – Strategic Assumption Surfacing and Testing). This involved identifying all of the important stakeholders (and listing their assumptions) and weighing their relative importance (p.58).

“Messy” problems

The fact that strategic problems may be interrelated, thus increasing the complexity of the problems, has led to the concept of “messy” problems (Vennix 1996, p. 1; Vennix 1999, p. 380)[15], i.e., an ill-defined problem resulting from a “situation in which opinions in a management team differ considerably” (Vennix 1999, p. 379). According to Vennix (1999), such situations arise from individual and social deficiencies in perception, memory, and communication (pp. 383-389).

Individual sources of messy problems are related to selective perception and selective memory based upon personal experience and formed expectations (Vennix 1999, pp. 383-384). This process results in forming illusions which, in turn, construct realities: “Everyday reality presents itself as an inter-subjective world which is shared with others (Berger and Luckmann 1966)” (Vennix 1999, p. 383). Social sources of messy problems are related to deficient patterns of social interaction and communication, which fail, in and of themselves, to demystify the illusions formed in the mental models of individuals (Vennix 1999, pp. 385-388). This process results in a ‘reality of multiple realities’: “Humans not only construct reality in their minds; their behavior also causes this reality in their minds to become reality in their environment… ‘If men define situations as real, they are real in their consequences’ (Thomas and Thomas 1928, p. 572)” (Vennix 1999, pp. 386 and 387).

According to Vennix (1996), sometimes people will not even agree that there is a problem, much less what it is (p. 13). Either way, in these situations, problems are quite ambiguous and intangible, as opposed to the idealized problem statement pursued in the micro-world view of model building. In this sense, one may argue that “there are no ‘objective’ problems, only situations defined as problems by people” (Vennix 1996, p. 13)[16].

Evolving problem definition and choice

The above discussion implies that when we are dealing with messy problems, it is, by definition, difficult to get agreement among different people on what is the problem to be modeled. Different participants will see the problem differently, and hold different priorities as to what are the most important issues. In a group model building intervention, the modeling-team will strive to move the group toward an agreed-upon modeling exercise, beginning with a particular focus on one issue, which may then evolve to link with or change to other, more pressing, important, central or dynamically relevant problems. As Andersen *et al.* (1997) indicate:

> The outcome of a group model-building process may differ considerably from what was expected at the outset... [This] results from the difficulty to diagnose readily and fully a client’s problem in advance of the group model-building intervention. Sometimes the “real” problem does not emerge until the group model-building process is underway. (p. 194)

[15] Citing Ackoff (1974, 1979).
[16] Citing among others Eden, Jones and Sims (1983).

In some cases, problem definition will rest simply in a matter of choice. This excerpt from Vennix (1996), reporting on the first session of an actual intervention, illustrates this situation of an evolving problem definition:

> After a brief introduction to the topic of system dynamics … the discussion was started with the identification of the problem to be modeled. Participants initially disagreed about the problem to be addressed with the model. One group member emphasized the new financial situation for housing associations… Another member of the group disagreed and explained the dangers in focusing on financial issues… A third view on the matter was… These three different purposes were discussed at length and it was difficult to arrive at an immediate choice for one of these three issues… it turned out that the third issue … would most probably lead to a very complex model… As a result, the group felt that it would be better to first focus on the other two goals. And rather than selecting one of these two, it was agreed that it might be interesting to use the model to try to find out how competitive these two objectives are by incorporating both into one single model… (pp. 205-206)

Obviously, in these situations, stakeholders are not simply identifying a "real" problem, and providing information or securing implementation of the modeling results. They are indeed defining and shaping the problem and the system, *as they come to jointly perceive it*. That is, the participants of the group model building intervention are constructing a socially negotiated order that can be best understood, in the form of this boundary-object called the model.

In working with social issues, do we know in advance when we're dealing with preexisting as opposed to messy problems? To what extent are we modeling reality, as opposed to a socially constructed order? If we knew, it would be easy to decide what to do. Unless we're working on simple problems, prior to having worked extensively on the problem, we probably don't know the answer to this question. Thus, important stakeholders are key to the modeling effort. This is because the modeling exercise becomes a venue for negotiation and alignment to occur. The way the problem gets defined depends on who's in the room. The elements in the model depend upon how the participants perceive and negotiate their reality. The model becomes a boundary-object in this negotiation. The model reflects what the group perceives as important elements to depict in the system, and to describe and tackle "their" problem.

Lack of agreement and the need for consensus building

Vennix (1996) argues that wide discrepancies among individual mental models of problems have detrimental effects upon organizational effectiveness:

> All else being equal, the larger the discrepancies between managers' mental models in an organization the more lack of shared vision, the more divergence in behavior and the higher the dispersion of organizational energy. This in turn impedes the effective operation of the organization, because it will induce a lack of cooperation. (p. 24)

Based upon the research of others,[17] he recommends that the most important goal in dealing with messy problems is the creation of a shared reality and problem definition among what he calls problem owners (Vennix 1996, p. 24).

In building system dynamics models, the lack of agreement on the problem being modeled, and the purpose of the modeling effort, will lead to not building a model at all, or building models of systems, as opposed to problems. Either outcome is less than ideal. Building a qualitative model (in the form of mapping and diagramming), or building a quantitative model of a system (but without a clear problem to solve) may still be worthwhile. Because it provides the participants the opportunity to learn from each other's perspectives, thus aligning their mental-models. While, at the same time, adding rigor to the discussion, providing them with means to keep track of complex causal structures, and serving as a group memory of their understanding (Vennix 1999, p. 382).

Some would argue that it is simply just useful to think about the problem in new ways, particularly if this new way of thinking can provide an added value in terms of problem structuring and/or perspective. In using system dynamics models in decision-conferencing, Reagan *et al.* (1991) indicated:

> Because the problem was complex and the implications of any policy change were uncertain, [we] constructed a system dynamics simulation model… [We] selected this modeling technique because it would expose the nature of the … system, make controversial assumptions explicit, and provide a common framework that would help policy makers develop a shared understanding of the problem… [However] the value of decision modeling to strategic thinking is primarily in the cognitive, social, and political activity of building the model, rather than in the completion of the model. (pp. 55 and 63)

Indeed, Stenberg (1980) suggests that once the problem has been defined, it is important that the client group perceives the problem as sufficiently relevant to warrant further modeling analysis (p. 308).

Difficulties in understanding social systems

Forrester began to investigate less tangible social systems (1969, 1971-B) shortly after conceiving the tools and methodology to model industrial dynamic systems (1961). He envisioned that system dynamics would be a useful tool to advance the knowledge of social systems, by exploring their dynamic nature (Forrester 1987-A, p. 136). Forrester indicated that social science had not advanced in step with natural science. He quoted Skinner (1971):

> Twenty-five hundred years ago it might have been said that man understood himself as well as any other part of his world… Today he is the thing he understands least. Physics and biology have come a long way, but there has been no comparable development of anything like a science of human behavior… Aristotle could not have understood a page of modern physics or biology, but

[17] Citing among others Eden, Jones and Sims (1983).

> Socrates and his friends would have little trouble in following most current discussions of human affairs. (p. 3)

Forrester believed that system dynamic models would raise the quality of the debate (1987-A, p. 147). System dynamics capable of tracing the complexity of social systems, would provide a means for improved communication and testing of people's mental models.[18]

Stenberg (1980) pointed out that this change in the field of application of system dynamics (to public policy) would have to be accompanied by an evolution in methodology (p. 292). He added, "the problems of integrating information gathering, modeling, and implementation are accentuated when we move into the area of public [social] policy" (p. 294). When Stenberg (1980) anchored his modeling work on the thinking of a group of key stakeholders, he scratched the surface in terms of identifying disagreements, potential conflicts of interest, and problems of communication in building a model that belonged to multiple constituencies. After quite a bit more experience with group model building, Richardson (1999) concludes:

> We know that building insightful system dynamics models is difficult and requires advanced skills in the modelers' arts and sciences; building insightful models with groups is made even more difficult by the intricacies of interpersonal communications, group process, and human relations. (p. 375)

This approach to system dynamics modeling is revealing the fragility of *our premises* in trying to understand social systems. Before we can set out course to solve "real" problems, we have to struggle upon a shared understanding of what real is. Also, for this very reason, group model building practice has resulted in deviation from classic system dynamics, in terms of modeling purpose.

<u>The multiple purposes of group model building</u>

While the main purpose of system dynamics, as argued by Forrester himself in *Industrial Dynamics* (1961), is to aid in designing better management systems, its application in group model building can be best understood when problems are perceived as emerging from debate and discussion, as opposed to preexistent. Therefore, group model building has also been useful in helping to create a shared perspective and understanding of the clients' issue. The model built by the group is viewed as a boundary-object subject to negotiation, and it is useful to the extent that it helps them reach agreement regarding the problem. The model also serves as a tool to investigate potential lines of action (Richardson and Senge 1989, Reagan *et al.* 1991). The model is useful to the extent that it helps the client group reach a consensual decision about what to do (Winch 1993).

From this point of view, a group model building intervention is a team-learning or organizational-learning activity in the sense that it seeks to achieve the above objectives by promoting alignment, and pursuing a shared-vision for the group, team or organization (Vennix

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[18] Both his methodology and findings, however, have been subject of controversy (Brewer and Hall 1973, Nordhaus 1973).

1994, Huz *et al.* 1997). If successful, the intervention can lead to commitment to and, eventually, organizational change (Akkermans *et al.* 1993, Vennix *et al.* 1993, Vennix *et al.* 1996). The new "reality" that is created can then be observed and assessed, i.e., the process starts all over again.

2. The dichotomy in model conceptualization

The second step of the system dynamics model building process is model conceptualization. I'll illustrate and discuss the dichotomy in model conceptualization in terms of four main issues: a) the role of the structuring-framework; b) knowledge elicitation and mental models; c) delineation of model boundary; and d) the role of the modeler/facilitator. Tables 6a, 6b, 6c and 6d, found attached in the Appendix, summarize my findings while mapping the literature into the dichotomy.

View of models as "micro-worlds"

<u>The goal is to test the dynamic hypothesis</u>

As previously stated, one of the end products of the problem identification and definition step is a preliminary theory accounting for the cause of the problematic behavior, called the dynamic hypothesis. According to Forrester (1961), the first objective of building a model is *to test* the dynamic hypothesis (pp. 56-57). In other words, the experimental world (the model) is designed to confirm or disconfirm the initial hypothesis, at least in the experimental setting: "We build a model to see if the mode of behavior could exist and whether or not it can result from the initial assumptions" (p. 450).

Randers (1980-B) suggests that the major creative step in model conceptualization is using the reference mode as "a catalyst in the transition from general speculation about a problem to an initial model" (p. 136). The goal of the conceptualization stage is envisioning the causal structure capable of reproducing the problematic behavior, as depicted in the reference mode (pp. 130-131). The actual test of the dynamic hypothesis is carried out when the model is formulated and simulated. But, model conceptualization involves explicit identification of the key variables, and of the key interrelationships among these variables, responsible for the observed problematic behavior.

The power of the system dynamics framework comes from its ability to examine the causes of behavior *endogenously*. Therefore, problematic dynamic behavior should be addressed with an endogenous theory capable of explaining the dynamics of a system through the *interaction* of the key variables represented in the model. Once the first objective –testing the dynamic hypothesis– is fulfilled (with an endogenous explanation), the model becomes useful in its second and main objective –system redesign for system improvement:

> By specifying how the system is structured and the rules of interaction (the decision rules in the system), you can explore the patterns of behavior created by those rules and that structure and explore how the behavior might change if you alter the structures and rules. (Sterman 2000, p. 95)

Sterman warns that the dynamic hypothesis is always provisional, subject both to revision or even abandonment (p. 95). In other words, it is a “working” theory that captures a present state of knowledge. Our knowledge, and its articulation in the form of a working theory, is subject to change due to learning from the experimental world, as well as the real world (pp. 88-89).

A rather simplistic yet useful way of characterizing the micro-world view of model conceptualization is describing it in terms of a *top-down approach* that seeks to conceive the key pieces of causal structure capable of reproducing key reference modes of dynamic behavior. The reference modes are the starting point to theory building. The dynamic hypothesis is a working theory of the feedback structures that supposedly will reproduce the reference modes of behavior. Once the model is formulated, the simulated behaviors are contrasted against the reference modes. The working theory is evaluated in terms of the closeness of fit between simulated and actual modes of behavior. The dynamic hypothesis is either confirmed or (partially or totally) rejected. In the latter case, model based learning suggests reviewing the working theory, and revising or reformulating the dynamic hypothesis, until a limited set of key pieces of causal structure are indeed capable of reproducing the key reference modes of behavior (based of course in a logical real world explanation).

Eliciting prospective *theories* and *facts*

Simulation models are conceptualized based upon information gleaned from the real world (Sterman 2000, p. 88), synthesized in the form of a mental model, that is, “an understanding of the operation of the real world” (Randers 1980-B, p. 119). According to Forrester (1961), active practitioners possess sufficient information to serve the model builder in conceptualizing an initial model:

> Searching questions, asked at points throughout the organization under study by one skilled in knowing what is critical in system dynamics, can divulge far more useful information than is apt to exist in recorded data. (pp. 58-59)

In group model building, the information upon which the model will be built has to be elicited from the *multiple* mental models of the client team. Sterman (2000) cautions that different members of the client team may hold different theories about the causes of a problem (p. 95). Forrester (1961) warns of the danger of the participants’ “wishful thinking” and “strongly formed past prejudices”, as hazards to successful model conceptualization (p. 452). The latter can be regarded as the problem of the difference between espoused theories and theories in use (Argyris 1999); and the issues previously referred to as selective perception and selective memory.

The micro-world view of model conceptualization stresses the importance of a factual based and empirically accountable model. If the basic assumptions built into the model are derived from the mental models of people, then:

> A good modeling process challenges the clients’ conception of the problem. Modelers have a responsibility to require their clients to justify their opinions, ground their views in data, and consider new viewpoints. (Sterman 2000, p. 85)

Parsimony and the dynamic hypothesis guide model boundary decisions

The reference mode(s) the model is meant to portray determines what to include or exclude from the boundary of the model's causal structure: "The reference mode helps the modeler focus on a specific phenomenon instead of ending in diffuse mapping of a system" (Randers 1980-B, p. 131). Thus, "the behavior of interest must be identified before the boundary can be determined" (Forrester 1975, p. 112). Also, the questions to be addressed in the model control the content of the model (Forrester 1961, p. 60), further shaping its boundary. Therefore, together, the definition of the problem and the purpose of the model, initially synthesized in the form of a dynamic hypothesis, should guide decisions regarding the boundary and scope of the conceptual model (Sterman 2000, p. 98). As stated by Forrester (1961):

> The initial hypothesis is part of the establishment of the initial questions and goals for the study. Without this initial mental and verbal model of the dynamic behavior being studied, there is no basis for deciding what factors might be important and which ones could be neglected. (p. 450)

For this reason, Forrester (1961) warns that lack of clarity of the dynamic hypothesis will subject the modeler to vulnerability to unessential complexity and detail (p. 453)

Classic system dynamics emphasizes (particularly at the stage of initial model development) the importance of parsimony, guided by choices based upon the dynamic significance of variables, made in the context of the study's purpose and problem. Richardson and Pugh (1981) advise to begin simply, containing complexity, and including in the model's boundary only those quantities that are perceived as dynamically significant for the purposes of the model, until a simple causal structure is well understood (pp. 43 and 61). Forrester (1975) recommends defining the boundary in terms of the smallest numbers of components needed to capture the essential dynamics and purpose of the study:

> One asks not if a component is merely present in the system. Instead, one asks if the behavior of interest will disappear or be improperly represented if the component is omitted. If the component can be omitted without defeating the purpose of the system study, the component should be excluded and the boundary thereby made smaller. (p. 112)

In *Industrial Dynamics* (1961), Forrester hypothesized that the novice modeler includes too much detail in the model, because he/she lacks the ability to discriminate if a particular factor is indeed necessary. While, alternatively, experience in building models leads to discovery of how much simplification is possible. He concluded that this problem boils down to a matter of degree (p. 453). And, he recognized that "defining the system boundary and the degree of aggregation are two of the most difficult steps in successful modeling" (in Sterman 2000, p. 100).

Nevertheless, classic system dynamics highlights the importance of parsimony in initial model development. By admitting only in the model improvement phase –i.e., "after the initial model passed generalized testing at an acceptable level"– that the model be extended and elaborated "to increase richness and realism through changes in system boundary, level of aggregation, or detailed formulation" (Randers 1980-B, p. 135). The most recent text in system dynamics reiterates this position:

> The art of model building is knowing what to cut out, and the purpose of the model acts as the logical knife. It provides the criteria to decide what can be ignored so that only the essential features necessary to fulfill the purpose are left… [W]ithout a clear purpose, there is no basis to say "we don't need to include that" when a member of the client team makes a suggestion. (Sterman 2000, pp. 89-90)

In fact, Sterman strongly advises:

> Modelers should not automatically accede to clients' requests to include more detail or to focus on one set of issues while ignoring others, just to keep the clients on board" (p. 85).

Forrester (1961) concluded that the key to success in determining the boundary and scope of a model lies in the modeler (p. 450). He suggested the modeler should be bold, yet fit the conceptual work of model development to his/her own skill, time, and experience.

Regardless the aptitude of the modelers, they should not disguise the limitations of their work (Sterman 2000, p. 98). An essential instrument, "surprisingly useful and shockingly rare", to reveal the boundary and scope of a model is a model boundary chart (Sterman 2000, p. 97-99). This is a three-column table that explicitly recognizes the results of discriminating thinking (dynamic-, problem- and purpose-based) regarding decisions about which key variables to model endogenously (first column), to model exogenously (second column), and to altogether exclude from the model boundary (third column). The model boundary chart allows model users to "decide for themselves whether the model [is] appropriate for their purpose" (p. 98). According to Sterman:

> Without a clear understanding of the boundary and assumptions, models constructed for one purpose are frequently used for another for which they are ill-suited [or even totally inappropriate]. (pp. 98-99)

Another important instrument to convey information regarding the boundary and level of aggregation in a model is the subsystem diagram (Sterman 2000, pp. 99-102). This is a macro view of the model showing the number and type of different organizations (agencies or sectors) represented, and how they are interrelated in the model. The subsystem diagram will only implicitly reveal information regarding endogenously, as opposed to exogenously modeled variables, and it says nothing about variables that have been excluded from the model. But it does convey a system's view of the model, that is absent in the three-column model boundary chart. Together, the model boundary chart and the subsystem diagram reveal the results of the modeler's systematic decisions regarding the boundary and scope of the model.

The modeler as an expert in the technology

The modeler brings to the group model building effort technological skills that must be exercised diligently and smartly. First, the modeler should view the problem and the system from the proper perspective: not too far, not too close (Forrester 1961, p. 451). To regard it from too great a distance is to neglect essential decision points, nonlinearities, and interconnections. To approach it too closely is to include too much detail, and to place too much importance on individual decisions as opposed to decision rules and policies.

Second, the choice of the time horizon of the simulation has significant influences upon the definition of the problem, and the evaluation of the policies under consideration (Sterman 2000, pp. 90-94):

> The time horizon should extend far enough back in history to show how the problem emerged and describe its symptoms. It should extend far enough into the future to capture the delayed and indirect effects of potential policies. (p. 90)

Sterman suggests that clients tend to underestimate time delays, think of cause and effect as local and immediate, and therefore propose time horizons that are far too short (p. 90-91). He concludes that the modeler must "guard against accepting the clients' initial assessment of the appropriate time frame" (p. 94).

Third, the modeler's expertise and experience in dynamically complex systems, and in modeling and simulation technology, are key to the development of a useful model. According to Forrester (1961):

> The skill of the person who undertakes to use a model is tested immediately –his first decision is to ask pertinent questions having important answers. (p. 60)

Fourth, the modeler should distinguish the actual state of affairs from mistaken or idealized perceptions of it, based upon the clients' biases and normative standpoints. In other words, the modeler needs to observe first-hand the system to distinguish espoused theories from theories in use (Forrester 1961, p. 452).

The list of potential contributions of the modeler as an expert in the technology is vast, and beyond the purpose of this section. The point to be made is that a *smart* system dynamics modeler can build a more insightful model than the client-group:

> The exploring (problem solving) task is both most central in the model-building process and least well-developed in the psychological literature. Some evidence suggests that well-trained or knowledgeable individuals can perform as well as or even better than groups. Simply put, a well-trained model builder can do as well as a group of model builders in tasks such as proposing formulations or designing feedback structures. (Vennix *et al.* 1992, p. 33)

For this reason, it is argued that the modeler has ethical and professional responsibilities, above and beyond his/her desire to work with and please the clients:

> The political context of modeling and the need to focus on the clients' problem does not mean modelers should be hired guns, willing to do whatever the clients want… As a modeler you have an ethical responsibility to carry out your work with rigor and integrity. You must be willing to let the modeling process change your mind. You must "speak truth to power," telling the clients that their most cherished beliefs are wrong, if that is what the modeling process reveals, even if it means you will be fired. (Sterman 2000, p. 85)

The technical expertise of the modeler should not be confused with substance-matter or content knowledge of the subject under study. While the modeler may know a great deal about the problem at the start of the intervention (or become very knowledgeable in the subject as a result of learning through the modeling process), the modeler should be regarded only as an *expert in the technology* (Reagan *et al.* 1991, p. 63). For this reason, particularly in the start of the intervention, the modeler is hard-pressed to learn as much as possible, and very quickly, from the client group, about the problem and its context. In the words of Sterman (2000):

> *Early in the modeling process*, the modeler needs to act as a facilitator [in the discussion among the client group], capturing [their] mental models without criticizing or filtering them. Clarifying and probing questions are often useful, but the modeler's role *during this early phase* is to be a thoughtful listener, not a content expert… Your goal is to help the client develop an endogenous [and valid] explanation for the problematic dynamics. (p. 95) [Emphases added]

When models are viewed as micro-worlds, the definition of "The Client" takes on a peculiar meaning:

> The client is not the person who brings you in to an organization or champions your work, nor even the person who pays for the modeling study, though it is helpful to have contacts, champions, and cash. *Your clients are the people you must influence for your work to have impact. They are those people whose behavior must change to solve the problem*… If your [paying] clients push you to generate a result they've selected in advance or that is not supported by the analysis, push back. If your clients' minds are closed, if you can't convince them to use modeling honestly, you must quit. Get yourself a better client. (Sterman 2000, p. 84-85) [Emphasis added]

View of models as "boundary-objects"

In the previous sections, I described the micro-world view of model building in terms of an intelligent and skilled modeler, who synthesizes in the form of a mental model information derived from the client group. A problem statement, reference modes, and a dynamic hypothesis provide the structuring-framework and guide the modeler, while he/she filters the information gathered from the clients, adjusting it with respect to potential problems from the participants' biases in perception, and wishful thinking. Prospective theories are contrasted, and facts are elicited. Theoretical inconsistencies and judgment errors on the part of the participants are handled by pursuing logical coherence, and correspondence with observed data, and concrete behaviors. Based upon the best mental model of the problem –that the modeler is capable of envisioning– a conceptual model is conceived. This model serves as the basis for model formulation, for the purpose of testing the dynamic hypothesis. In other words, for the purpose of testing the theoretical explanation for the problematic behavior.

In the following sections, I'll shift attention to the boundary-object view of model building, previously discussed in terms of the existence of multiple constituencies and socially constructed problems. I'll begin by collecting the evidence that while we may be interested in eliciting *theories* and *facts*, we may actually be eliciting merely *views* and *opinions*. Second, I'll raise the issue of the role of structuring-frameworks in knowledge elicitation. What kind of, and how much structuring should there be in the elicitation process? Third, I'll address the consequences of the answer to this latter question, in terms of issues dealing with model scope and boundary. I'll conclude the illustration of the dichotomy in model conceptualization by discussing the role of the modeler in the boundary-object view of model building, which is related to the issue of group-ownership, as opposed to modeler-ownership of the model.

Eliciting *views* and *opinions*

Roberts *et al.* (1983) argued that it is impossible to identify the components of any system without a clear idea of what the problem is, and *who is interested in the problem* (p. 26). There is more to this argument than the previously discussed idea that the clients define the problem.

Who's interested in the problem also determines the knowledge base to tackle the problem, and has a great deal of influence in shaping the boundary of the model. According to Morecroft (1994), individual mental models play two roles in the modeling intervention. They are the source of knowledge and information in environmental scanning, and they give shape to the groups debate and dialogue (pp. 7-8). Consequently, varied mental models based upon whatever knowledge the participants have –"real or imaginary, naïve or sophisticated"– enter the debate and give final shape to the group's collective view of the system, determining their future actions (p. 7). In group model building, it has been acknowledged that the intervention depends "on the *thoughts and agendas* the client group itself brings to the workshop" (Richardson and Andersen 1995, p. 133). [Emphasis added]

Figure 5, copied from Morecroft (1994, p.10), underscores the fragility of the notion that one can readily elicit *theories* and *facts* from the mental models of participants. On the top, right-hand corner of the picture, a deck of cards illustrates the knowledge base and mental models of the participants. Each dot represents a fact that a participant carries in his/her head. Small rectangles represent learned concepts or perceptions of social and political factors. An individual's knowledge base of facts and concepts is extensive, and contingent upon the individual's singular collection of experiences. The network of facts and concepts, as illustrated in a single card, composes the individual's mental model. The mental models are activated in the process of recognition of strategic issues, or problem issues. They shape debate and dialogue, and are in turn shaped by the exchange (of knowledge, facts, concepts, and networks of facts and concepts) with other participants, facilitated by the modeling team. (Therefore, these individual mental models are not static, but changing over time.) The structuring-framework adopted in the intervention influences the exchange among participants. A modeling team or facilitator intermediates the whole process (pp. 5-11).

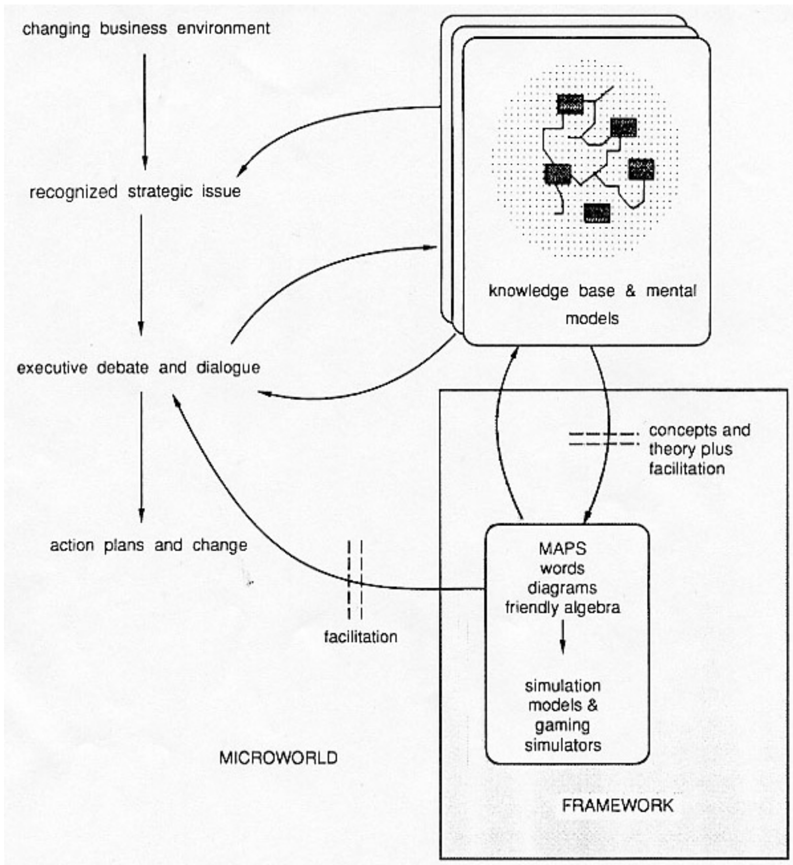

Figure 5. Knowledge base and mental models, debate and dialogue
(Copied from Morecroft 1994, p. 10)

As a result, the development of a shared mental model depends, quite literally, upon "who's in the room". The replacement of the deck of cards (participants), the choice of structuring-framework, a change in the modeling team or of facilitator, all have potential implications in terms of the construction of a problem definition, of knowledge elicitation, and of agreed-upon causal explanations. In conceptualizing a model based upon this shared mental model developed during the intervention, the resulting model can not be seen as cast in stone.

If we accept the notions proposed by Lane and Morecroft:

> If the model is indeed a representation of a client's idea on how the world functions, then this microcosm, or microworld, is the *transitional object* upon which the experimentation is performed. (Lane 1994, p. 100) [Emphasis added]

And

> [P]eople learn effectively when they have *transitional objects* to play with in order to develop their understanding (or refine their mental models) of a particular subject or issue. The combination of transitional objects, learner, and learning process is what Papert [1980] calls a microworld. (Morecroft 1994, p. 11) [Emphasis added]

Then, we may extend this notion by implying that a transitional object that is found acceptable to a group of people becomes a *boundary-object* that reflects the group's negotiated representation of reality (i.e., a socially negotiated order). This is why it is so consequential that the *key* members involved in an important decision-making process be in attendance of the intervention or workshop. Quinn *et al.* (1985) add, "[a]ttendance of *all* key members ensures not only *appropriate expertise and input, but also understanding and commitment*" (Quinn *et al.* 1985, p.53). [Emphases added]

When a group of people assembles, as depicted in Figure 5, in a group model building intervention, to make a decision, or to develop an action plan, around a problem or issue, there are many sources of, and reasons for disagreement. If they are conceptualizing a model, they may disagree in several points of the conceptualization process: problem definition, selection of key variables, interpretation of variables (concepts and constructs), appropriateness of reference modes (particularly if they are not based upon time-series data), causal theories, inputs to rate equations, and parameter values. The participants may disagree for several reasons: selective perception/memory, different political points of view, wishful thinking, uncertainty and/or ignorance.

The way to resolve disagreement within the client group may be contingent to the locus of, and reasons for disagreement. A political disagreement around problem definition may be resolved through negotiation. While, different causal theories may be contrasted and tested using the model as a laboratory. But, because often people simply don't know how some processes function,[19] it is easier to accept the notion that we're eliciting views and opinions, as opposed to theories and facts. If this is the case, and if participants of the intervention hold quite different views and opinions, rather than eliciting people's theories as a starting point, it may be more useful to elicit their views of the system. This will be discussed in the next section, in terms of a *bottom-up approach* to model conceptualization.

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[19] For example, in a model conceptualization exercise, Vennix and Gubbles (1994) admitted:

> Although there was consensus on many issues, it also became clear that several processes in health care are poorly understood. Here the knowledge elicitation process was arrested at the point where there were only vague conjectures. (p. 138)

In eliciting parameter values, Richardson and Andersen (1995) found:

> The parameter elicitation exercise was surprisingly crucial, not only providing input to the modeling effort but revealing areas of uncertainty, disagreement, and actual ignorance among these experts on foster care, which pointed toward the need for further work. (p. 117)

What kind of structuring-framework, and how much structuring?

This section builds upon an assumption, that instead of being told or taught, people learn through discovering for themselves (Morecroft 1994, p. 4). In other words, people make up their own minds (de Geus 1994, p. xiv). It discusses how a structuring-framework to learning (an example of which is the system dynamics model building process) imposes constraints and biases, leading people to learn particular things, in particular ways (Morecroft 1994, Lane 1994). I review authors who argue that these biases need to be minimized, particularly early on in the intervention (Lane 1993, Richardson and Andersen 1995).

Building a model around a dynamic hypothesis introduces a strong bias in model conceptualization. Therefore, I suggest that some modelers often adopt a *bottom-up approach* to model building, constructing (with the client group) a broader shared view of the system. Rather than holding a narrow focus (in model conceptualization) on the dynamic hypothesis (Vennix *et al.* 1988, 1990; Vennix and Gubbles 1994; Morecroft *et al.* 1991; Richardson *et al.* 1992; Richardson and Andersen 1995; Lane 1994; Wolstenholme 1994). I explore the role of the model in these cases (if it is not to test the dynamic hypothesis!).

Toward the end of the section, I survey a view of the role of structuring-frameworks that suggests that they are necessary, but they need to be used selectively. Different cognitive tasks require different structuring-frameworks (Richardson *et al.* 1989, Vennix *et al.* 1992/94). A group model building intervention is composed of a repertoire of sub-frameworks, wisely used, embedded within the larger method, called system dynamics model building (Lane 1994, Vennix 1996, Andersen and Richardson 1997). An effective intervention is one that appropriately matches the series of model building tasks with the best structuring-procedures for knowledge elicitation and group dialogue.

In general, this section is about how models can be useful in a dialogue, and how people can learn through building a model together. It addresses the complex issue of providing the client group with frameworks that are helpful in carrying this dialogue, without biasing it. I argue that the central idea is that the model serves as a boundary-object in the dialogue. While the model may be more or less useful in informing a policy-making context, the goal is not necessarily to find the answer to a problem. The goal is having the client group share a common language (Lane 1994), a common view of the system (Morecroft 1994), generate and test ideas and scenarios (Morecroft *et al.* 1991), and build consensus and support around an action plan (Vennix 1994).

WHAT IS A STRUCTURING-FRAMEWORK? Morecroft (1994) distinguishes models in terms of three attributes: 1) *maps* that capture and activate knowledge, 2) *frameworks* that filter and organize knowledge,[20] and 3) *microworlds* for experimentation, cooperation, and learning (p. 3).

[20] The use of the word framework in different contexts and with different meanings throughout this paper is bound to create some confusion. Because of Morecroft's (1994) use of the term, distinguishing *frameworks* from *maps*, I chose to refer to the general class of frameworks –approaches to organizing knowledge– as *structuring-frameworks*. The latter includes research methods (e.g., system dynamics), approaches (e.g., group model building), and frameworks (e.g., feedback-loop causal diagrams), as well as mapping tools (e.g., influence diagrams), lists, and other less structured (or naturally structured) means of organizing knowledge (e.g., Hodgson's [1994] hexagons). A top-down approach to organizing knowledge filters and fits information into a method or framework for a given

He proposes that each supports different cognitive tasks and group processes. The most obtrusive use of a model is as a framework. They combine maps with concepts and theories. They add structure imposing logical constraints:

> Whereas a simple list just captures items of knowledge, a framework packages and organizes knowledge. A framework also filters knowledge because some ideas won't easily fit within the constraints of the framework… So although modelers often say nowadays that they are mapping mental models, really they are not. They are filtering and organizing from mental models to fit the modeling framework. (pp. 9 and 11)

Because frameworks can introduce bias in knowledge elicitation from, and discussion among the client group. First and foremost, it is important to establish which framework will best fit the cognitive needs of the client group (Morecroft 1994, p. 11; Lane 1994, p. 104).

Lane (1993) recommends using "flexible" approaches to generate, select and study the clients' issues, with the goal of reducing any bias in the elicitation process toward the system dynamics modeling method (p. 239). He argues that this allows the participants to frame their problem in the most appropriate structuring technique (p. 240). This is particularly important in the early stages of an intervention. Richardson and Andersen (1995) describe how simply "explaining the mysteries of system dynamics or of a particular model formulation can get in the way of uninhibited group discussion focused on the problem independent of approach or formulation" (p. 132).

Among group model building practitioners, the mere use of a simple "concept model" as a starting point of a conceptualization session already draws suspicion of introduction of bias in knowledge elicitation and model conceptualization:

> One might also question the extent to which the concept model driven by three time series … biased the group in the main two-day workshop toward exogenous formulations. (Richardson and Andersen 1995, p. 135, footnote number 10)

It is important to highlight that the role of "concept models" is simply to introduce the system dynamics framework (and its icons), to demonstrate the connection between causal structure and system behavior, and to initiate discussion regarding the "real" system (Richardson and Andersen 1995, p. 130). These models are *not* intended as preliminary versions of (endogenous) causal structures addressing a dynamic hypothesis! Interestingly, I could not find evidence in the group model building literature,[21] of models built around a dynamic hypothesis. If this was the case, the authors may have unconsciously omitted this fact.[22]

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purpose. A bottom-up approach begins with instruments (e.g., hexagons) that allow for more spontaneous surfacing and organization of knowledge (generating lists and naturally forming clusters), and gradually builds in the direction of the most appropriate framework to tackle a given problem.

[21] Group model building cluster of readings listed in the Appendix (number 5).

[22] I suspect this to be the case, and it may have to do with the issue of client-ownership, discussed toward the end of this paper.

A BOTTOM-UP APPROACH TO MODEL BUILDING. I characterize the boundary-object view of model conceptualization as a bottom-up approach to model building, and I take the liberty of drawing upon published work in system dynamics to illustrate it (Vennix *et al.* 1988, 1990; Vennix and Gubbles 1994; Morecroft *et al.* 1991; Lane 1994; Wolstenholme 1994; Richardson and Andersen 1995). I do not mean to imply that these authors take a pure boundary-object (or bottom-up) approach to model building. But, this work does provide a sharp contrast with the pure micro-world (or top-down) view, as I have defined it, in terms of a narrow problem statement, a set of key reference modes, and –most importantly– a dynamic hypothesis, guiding the elicitation and model conceptualization phase of the modeling process.

The bottom-up view of model conceptualization does not ignore reference modes, and their critical role in model building and validation. In fact, reference modes are an integral part of the problem definition phase. But, it tends to put them aside for a moment, in the model conceptualization phase, and it concentrates first upon building a shared view of the system (in terms of its conceptual structure). It de-emphasizes the (endogenous) model as a structuring-framework, and uses it more simply as a mapping tool. As an example, I quote Morecroft's (1994) description of Wolstenholme's approach to model conceptualization:

> The modeler collects fragments of structure that, to begin with, are just lists of key resources, states and resource flows. Lists are a good way to capture managers' [own] categories and concepts. These particular lists also generate raw material for an influence diagram. Wolstenholme's [1994] approach gently shapes a discussion first into a list and then into a diagram that eventually shows feedback loops, delays, and organizational boundaries. (p. 23-24)

An alternative approach can found in Lane (1994, pp. 107-114).

Once a model is formulated, the simulated behaviors can be contrasted against the reference modes. The dynamic hypothesis plays a minor role in model conceptualization, and inferences regarding the causes of particular behavior surface from exploring the consequences of the causal structure that was created (e.g., Richardson and Andersen 1995). Initial causal theories are revisited in light of the conceptual model (e.g.: Lane 1994, p. 111). This approach often results in a different understanding and definition of the problem (e.g.: Vennix *et al.* 1990, p. 204-205; Vennix and Gubbles 1994, p. 140; Lane 1994, p. 112).

In practice, this approach is exercised in many different ways, with more or less emphasis upon the role of the reference modes, and of a dynamic hypothesis, in model conceptualization. But the general idea is that less emphasis on modeling as a framework allows for a richer, less filtered elicitation and discussion, thus limiting the bias of the method in the results of the work. This approach focuses upon the model as a tool for group dialogue and alignment. It recognizes that a bulk of the problems confronting managers and policy makers are political in nature (Lane 1990, p. 93):

> The reality is that any problem is embedded in a network of political, cultural and power relationships. It is naïve and futile to imagine that these can all be cut through because a solution is known to be mathematically optimal. Any solution

> that requires action to be taken will need to address the relationships of those involved, account for them, and take time to organize their re-configuration. (p. 90)

Therefore, problem solving requires among other things creativity, in the form of idea and scenario generation, and exploration (de Geus 1994, p. xv; Lane 1994, pp. 110-113; Morecroft *et al.* 1991).

This approach to building a conceptual model generates useful policy relevant information (Vennix and Gubbles 1994, p. 139; Eden *et al.* 1983), and it also enables the client-group to share their mental models. It helps them develop a common language and a shared understanding. As illustrated in Lane (1994):

> The tool was found useful for analyzing ideas and generating insight… One of the team members … commented that the discussions had allowed him to produce much information that might otherwise not have been captured in such an organized form. As a result, he believed, the team would be able to use its shared understanding [of their problem of interest] much more effectively as they had a common language in which to describe it. (p. 110)

It helps them know better what they already knew:

> By expressing such a mental model in some external form, we can help a client use effectively a much greater proportion of the knowledge that they possess… The most widely used reasons for creating an external representation of mental models is the great benefit that can be gained by [naturally] structuring and sharing information. (p. 100)

According to Morecroft (1994), the most informative work about the process of mapping in the context of groups originates in the group decision support literature (p. 5). The decision conferencing tradition is related to, and draws extensive upon, the group decision support literature (Rohrbaugh 2000). In this vein, Milter and Rohrbaugh (1985) synthesize the role of the model as a "decision accounting system" (p. 221). This means that the model captures and reflects the results of the series of systematic decisions made by the group during the process of elicitation and discussion (Quinn *et al.* 1985, p. 55). Thus, the group uses the intervention to give form to a problem/system. The "working" model serves as a boundary-object for discussion and negotiation. The "final" model reflects the result of the group's structuring-decisions. The model is the closest thing to a concrete reality shared by the group. It is *their* representation of *their* reality. Nevertheless, it is the group's socially negotiated order.

Taken literally, this may suggest that in some cases there is only marginal gain in actually formalizing and simulating the model. Most of the benefit from model building results simply from model conceptualization:

> [T]he process of model building is frequently more important then the resulting model. Model building itself is largely a learning process about the problem. Most

> insights about the characteristics *of an ill-structured problem* are gained during the iterative process of designing a computer model, rather than after the model is finished. (Vennix and Gubbles 1994, p. 122) [Emphasis added]

***SCRIPTS* TO GROUP MODEL BUILDING.** While it is important to use flexible approaches to study the clients' issues, thereby reducing bias associated with forcing the problem through a particular frame. One must not forget that there are good reasons why research methods and analytical frameworks are brought to bear upon problems. Reagan *et al.* (1991) explain why a host of modeling techniques are used in decision conferences:

> Decision models are intellectual tools that have been developed to make unwieldy problems more manageable by structuring thought processes, clarifying interrelationships, and handling complex data. These tools make the policy-making process more efficient by enabling policy makers to rapidly integrate and analyze information and options and make it more effective by enabling them to examine policies and their implications thoroughly. (p. 53)

System dynamics, in specific, is perceived as particularly useful in exploring and understanding the endogenous causes of problematic dynamic behavior, embedded in feedback rich, complex systems (p. 54).

Hence, if the appropriate modeling technique is chosen to handle a problem, too much flexibility may get in the way of learning about the problem. For instance, Richardson and Andersen (1995) recognize that being too careful about the group process may have yielded disappointing analytical results in a particular intervention:

> The modeling team pressed for some causal feedback views but did not force an endogenous dynamic feedback view. In the end, the [client] team was left with few insights about the causal structure of critical parts of the system… [This] model-based group work might be faulted for trying to be too responsive to the group, and for failing to do a good job presenting and motivating the system dynamics approach. (p. 133)

Research in the field of cognitive psychology revealed that knowledge elicitation and problem analysis involve distinct cognitive processes related to three general types of tasks: eliciting information, exploring courses of action, and evaluating situations (Richardson *et al.* 1989, pp. 346-347; Vennix *et al.* 1992, pp.29-30; Andersen and Richardson 1997, pp. 111-112).

Eliciting information, also referred to as intelligence, production, or conceptual behavior, is best accomplished using a *divergent* structuring-framework. Divergent thinking is useful in system dynamics modeling, for example, when exploring problem definition and alternative causal explanations (Richardson *et al.* 1989, p. 346; Lane 1994, p. 104). Exploring courses of action, also referred to as problem solving or design, is a different cognitive task requiring a *convergent* structuring-framework. This type of structuring-framework is useful in revealing feedback paths and formulating rates (*Ibid*.). Finally, the two forms of evaluation are judgment and choice. Judgment has to do with assessment on a scale, as in the case of parameter estimation. Choice has to do with selecting one or more options from a set, as in the case of assessment of the performance of different policies (Richardson *et al.* 1989, p. 347).

Therefore, Andersen and Richardson (1997) argue that the key to successful group model building "is selecting the most appropriate type of group structure and group task for each point in time in the modeling conference" (p. 111; see also Vennix *et al.* 1992/94). For this reason, these authors have begun to develop "scripts" for group model building –"sophisticated pieces of small group process" (Andersen and Richardson 1997, p. 107), "planned and rehearsed for accomplishing subgoals in the course of a group model building workshop" (Richardson and Andersen 1995, p. 130).

Andersen and Richardson (1997) suggest a number of scripts for problem definition, system conceptualization, parameterization, data estimation, idea generation (policy alternatives), and model refinement. In these scripts, they've tried to match the nature of the cognitive tasks with the most useful and least obtrusive structuring-frameworks. A sequence of scripts thoughtfully used in an intervention generates useful products to the client-team, such as "a stakeholder analysis, a precise description of a problem to be solved, a sketch of model structure, or the determination of a set of actions to be taken" (p. 108).

<u>Dealing with scope and level of aggregation</u>

In the micro-world view of models, the issue of delineation of model boundary has been characterized as a difficult task to be handled by the modeler, guided by as clear as possible dynamic hypothesis, and driven by parsimony. In contrast, in the boundary-object view, the minor role of a dynamic hypothesis in model conceptualization, coupled with a decision to depict the system in richer detail, and deference to the client-group, raises some critical issues regarding how to make judgments about model scope and level of aggregation.

Forrester (1961) conceded that some detail, "even when it does not affect system performance, is justified in order to provide apparent reality and easier communication" with the modeler's client or audience (p. 453). Vennix and Gubbels (1994) considered an improvement in quality in their initial model –in terms of reduction of ambiguity– the fact that the number of variables in the model doubled, when the model was worked on by the client group:

> [B]uilding a conceptual model often generates very useful policy relevant information… In our case several tangible results materialized from this conceptual model building stage. These are related to the quality of the conceptual model, the definition of the policy problem, and the structuring of future research efforts… [T]he quality of the conceptual model was increased drastically on a number of aspects, first, with regard to the number of variables included… Although a larger conceptual model is not necessarily better, the increase was primarily caused by refinement of the concepts and relationships… (pp. 139-140)

The willingness to depict the system in richer detail, guided by the desire to have the client group share a common language, and a common understanding of the problem, is also characteristic of Lane's (1994) "Modeling as Learning" approach:

> [A]s models are revisited, variables are seldom dropped, it being far more likely that intermediate variables are added to clarify the nature of the causality. (pp. 102-103)

In a similar vein, the interventions described in Richardson and Andersen (1995) portray an evolution in model structure, driven by the client group, to incorporate more and more structural detail to the conceptual models (pp. 116-129). The authors noted:

> The obvious malleability of the models, and their partial fit to the mental models of the participants, led to a laundry list of concepts and variables the group wished to see incorporated into a full model useful for forecasting and policy. (p. 121)

So, if the client group is not somehow contained, they are likely to push the modeling team in the direction of incorporating into the model every institutional actor and relationship perceived as even of modest importance in their system. Instead of acceding to modeling one problem, the client group will wish to examine several issues. The client group will also be interested in how these issues are interrelated.

In addition to willingness to depict the system in richer detail, the second important characteristic of the boundary-object view is greater deference to the client group, in terms of decisions regarding model scope and boundary. Lane (1994), for instance, requires the clients to choose *one* issue to be addressed in the model, but then gives the clients considerable discretion in deciding what issue they want to address, and what's important in addressing this issue:

> [W]e should not try to model a system since there is no end to the effects that should be included… [I]n order to put a boundary on the effects to be included … we model only one issue. We place the issue in the context of a system and then include only those aspects of the system that the *client* considers to be important or that they wish to concentrate their study on. There is no a *priori* requirement of certainty regarding quantification, or even cause and effect. The very discussions that take place around such points are part of the process, part of the deliverable. (p. 96)

If the dynamic hypothesis does not act as the "logical knife" in the hands of the "savvy" modeler, in the delineation of the model's boundary, then, how are judgments made about model scope and level of aggregation? Well, first, it is probably *not* true that modelers give up, fully and willingly, their ability to use their system dynamics' expertise, and their modeling experience, in favor of the clients, in makings judgments about model boundary. More likely, the existing literature does not reveal the subtleties in this modeler-client relationship, in which the modeler certainly exercises a great deal of influence upon the client group, nurturing and guiding the group's decisions. While at the same time, providing the clients with a sense of power and ownership about the decisions that are being made.

Nevertheless, in contrast with the micro-world approach, which recommends attention primarily (or even solely) to the behavioral implications of the structural elements in the model

(Forrester 1961, p. 112). The boundary-object approach relies also upon a mix of group techniques to force the client group to make simplification decisions on model scope and level of aggregation. For instance, the separation of the roles of modeler from group facilitator allows the modeler to take the onerous task of proposing simplifications to the group. While the facilitator gives the group the option to take the modeler's advice, or not, but urges the group to listen to the modeler, because he/she is an expert in the technology, and a smart systems thinker (Richardson and Andersen 1995).

There are several examples in the literature, where the Delphi and the Nominal Group techniques are used to induce the group to make tradeoff decisions, ranking in importance, for instance, key variables to be included in the model (Vennix and Gubbels 1994, Rohrbaugh 2000). Of course, these techniques are useful in several other situations, such as deciding which strategic issue to focus upon, which policy alternatives to explore, parameter estimation, model calibration, and evaluation of policy outcomes (Rohrbaugh 1979, 1981; Richardson *et al.* 1989; Vennix *et al.* 1992/94).

While the "art" in group model building, in the micro-world side of the dichotomy, lies in large part around the issue of conceiving the dynamic hypothesis, departing from problem identification and model purpose. It seems to me that, in the boundary-object side, it is related to this issue of delineation of model boundary. If experienced micro-world modelers explained how they leap from problem definition to model conceptualization, and if experienced boundary-object modelers described how to deal with scope and level of aggregation, then "more science *would* be added to the group model building craft," to paraphrase Andersen *et al.* (1997).

The tension between the micro-world and the boundary-object views, regarding the delineation of model boundary, is closely related to a more significant tension having to do with what one considers a "good" model. Is a good model one that parsimoniously captures the dynamic behavior of the key variables in a system, based upon an endogenous causal structure? Or, is it a model in which the participants see themselves, and share an understanding of the nature of the interrelationships of key variables in their system?

<u>The modeler as facilitator; the issue of ownership</u>

In "Modeling *for* Learning Organizations," Morecroft and Sterman (1994) argue there is now a "modern" view of modeling that repositions the role of the model and of the modeler. Models are "owned" by policymakers, not by technical experts. They are created in a *process* in which the modeler is, in part, a *facilitator*, "one who designs and leads group processes to capture team knowledge" (p. xviii). This view is based upon the recognition of the fact that while the model is an intellectual and analytical tool, the *process* of modeling is social and political (Reagan *et al.* 1991, p. 53).

A pragmatic understanding –that insights from even the most well developed models are unlikely to be implemented– supports it:

> I have not met a decision maker who is prepared to accept anybody else's model of *his/her* reality, if he knows that the purpose of the exercise is to make him, the

> decision maker, make decisions and engage in action for which *he/she* will ultimately be responsible. People (and not only managers) trust only their own understanding of their world as the basis for their actions. "I'll make up my own mind" is pretty universal principle for everyone embracing the responsibility of their life… (de Geus 1994, p. xiv)

According to this view, the consultant modeler should avoid wearing the "expert hat". Instead, he/she should act as a "facilitation consultant," offering "a process in which the ideas of the team are brought out and examined in a clear and logical way (Lane 1994, p. 93). His/her role is to "activate" the participant's knowledge and mental models (Morecroft 1994, pp. 8-9). This role:

> … is simply to encourage clients to put forward their ideas, to clarify them if necessary, and to record them in a form that is both permanent and transferable. (Lane 1994, p. 96)

Lane's (1994) "Modeling as Learning" approach supports client ownership of all analytical work, modeler acting as a facilitator, and predomination of "soft" analysis. The model is labeled as an "articulated model" (p. 96). Perhaps, a close parallel to the "boundary-object" type model. Here, even well known generic feedback structures need to be used with care, to avoid loss of client ownership:

> [W]e do not suddenly produce these large structures and give them to clients; this would be against the whole philosophy of the approach. Instead we read around the client's problem to check whether there are any useful structures in existence and, if so, slowly introduce helpful pieces to the client during the process of model building. This process may not be as fast as just conjuring up a large model, but it does ensure ownership and the benefits that flow from it. (p. 106)

***TEAMWORK* IN GROUP MODEL BUILDING**. The dual role of the consultant as modeler and facilitator has long been recognized in the decision conferencing literature (Milter and Rohrbaugh 1985, p. 222; Quinn *et al.* 1985, p. 53). A way to balance the modeler and facilitator roles of the consultant is to assign them to different members of a *modeling-team*. The decision conferencing tradition influenced group model building, leading Richardson and Andersen (1995, see also Richardson *et al.* 1992) to identify five roles in group model building. (In addition to the facilitator and modeler, they also highlight the roles of the process coach, the recorder and the gatekeeper.)

These authors hypothesized that all five roles must be present for effective group support. While some of these roles may be combined, their explicit recognition and deliberate assignment to skilled practitioners can significantly accelerate the group's modeling effort (p. 115). They warn, however, against combining the roles of facilitator and modeler:

> [T]he more powerful minimum is not one person enlightened by perceiving several essential roles but at least two people in a group modeling team, one focusing on group facilitation, knowledge elicitation, and initial drafts of

> structure, and the other focusing on the problem, the system being conceptualized, real-time refinements of structure, and emerging insights. (p. 129)

Richardson and Andersen's approach suggests that in resolving facilitator/modeler conflicts, the bias is in favor of the facilitation role. The facilitator has the lead role. He/she is the organizer and conductor of the group process, and "on stage and vulnerable" for most of the group meeting time. The modeler and the process coach serve as *content* and *process* coaches respectively:

> We have chosen the word *coach* advisedly –a coach does more than diagnose problems; a coach suggests plays. And great coaches make their suggestions with deep knowledge of the situation in the game and all the players' strengths and weaknesses. (p. 132)

THE MODELER AS REFLECTOR. "Teamwork in Group Model Building" (Richardson and Andersen, 1995) polishes the role of the system dynamics modeler:

> [T]he modeler/reflector [acts] not as a master modeler but more as a reflector on the group's discussion, a "contemplator" whose job [is] to refine and crystallize the thinking of the group. We came to understand that the role of the modeler/reflector is more general than that of modeler and that there is great value to having a person reflecting on the group's thinking and reflecting it back to them. The modeler/reflector can perceive subtleties the facilitator might miss, can identify linkages and systems insights that emerge only from reflection, and can punctuate the discussion with points of important emphasis. (p. 124)

This approach does *not* allow for the modeler to claim ownership of (or responsibility over) the client's model. As described in Reagan *et al.* (1991):

> The analyst [modeler] function[s] as a critical outsider whose role [is] to ask penetrating questions, show the decision makers how to think about the problem in new ways, discover and resolve inconsistencies, and enhance the decision makers' emerging understanding (p. 55).

They add:

> It is often quite difficult for those decision makers to place their trust in an unfamiliar modeling technique and depart from their accustomed ways of thinking about the problem. Yet it is this process of rethinking the all-too-familiar problem in an unconventional way that contributes substantially to improved decision making. (p. 63)

The role of the modeler/reflector is to best fit the problem at hand so that it may be analyzed within the chosen method of analysis. The role of the facilitator, on the other hand, is to make sure that problem identification and elicitation are not biased in the direction of a particular method, but accommodated into the most adequate framework. In this balance, the skilled modeler is "the one who can best merge problem definition and specification assumptions [e.g., selection of levels, identification of causal paths, formulation and parameterization of rate equations] so as to capture the underlying social reality in an insightful and useful manner" (Andersen 1980, pp. 63-64). The skilled facilitator is the judge who draws the line beyond which the work of the modeler becomes intrusive (biasing the analysis or alienating the client). The facilitator prevents the modeler from taking model ownership away from the client.

Preliminary findings and discussion

In mapping the literature in the group model building genealogy into the conceptual dichotomy proposed and defined in this paper, I've found supporting evidence to the thesis that there may be two intertwined threads in this new approach to system dynamics modeling involving a group of people in model construction. Group model building interventions strive both to create a shared understanding of an interpersonal or inter-organizational problem, in the form of a "boundary-object" model, and to build a "micro-world" type model that is useful in terms of organizational redesign.

In the problem identification and definition phase of the modeling process, the extent to which the modeling team moves from a boundary-object to a micro-world type model depends upon the clarity of the focus of the intervention. This, in turn, is shaped by the degree of convergence in the management team, regarding the problem to be modeled and the purpose of the intervention.

Drawing upon the terminology of the CVA framework, I'd argue that at the start of the intervention, one should regard the model as a boundary-object, and should stress the *instrumental* dimension (see Figure 2), balancing the political with the consensual perspectives. If there is convergence within the group, leading to clarity and focus in problem definition, one should begin to regard the model as a micro-world, and shift attention to the *consummatory* dimension, balancing the rational with the empirical perspectives. The point of transition between building a boundary-object or a micro-world model may be best understood in terms of the parturition of a clear statement of the dynamic hypothesis.

The use of the dichotomy in looking at the problem definition phase of the modeling process also served to explain the reason for the multiple purposes in group model building. The "disconnect" between the classic system dynamics approach, emphasizing policy change and organizational redesign, and the varied purposes of group model building interventions (alignment, building commitment, decision making) is not in the goals themselves, but in the nature of the client/audience. Before a client group is ready to engage in informed policy change and organizational redesign, multiple constituencies and messy problems require preliminary and intermediate steps in problem definition and analysis. Perhaps, prior to changing the decision rules and causal structure of a system, the group needs to agree on shared strategies, goals and objectives.

In the model conceptualization phase of the modeling process, the "bridge" between the two modes of operation appears to be related to the discussion regarding *knowledge elicitation and mental models*. This, in turn, may be shaped by several factors, among which those identified, by Quinn *et al.* (1985), as: 1) disciplinary and methodological biases, 2) personal values, and 3) situational demands (p. 51). For example, a "hard" system dynamicist, and/or a clearly defined problem and focused purpose for the intervention may shift the model building task toward a micro-world type model. This implies eliciting *theories* and *facts* from the participants, and using a *top-down approach* to model building. Alternatively, a "soft" system dynamicist, and/or a messy problem embedded in an environment characterized by high degree of uncertainty may shift the model building task toward a boundary-object type model. In this case, the modeling team searches for the group's *views* and *opinions* using a *bottom-up approach* to model building.

More likely, there is *no* pure top-down or bottom-up approach. Instead, a mix of the two is used in ways that are not clearly explained or understood. Experienced modelers probably draw upon both approaches. They probably attempt to elicit theories and facts, while being skeptical about views and opinions. They probably strive for the most parsimonious endogenous feedback-rich model, while capturing the client's system with as rich as necessary view that the participants can agree upon and share. In essence, they strive to draw upon their technological knowledge and modeling experience to build an insightful model, while at the same time keeping the clients on board and shifting as much model ownership (and learning) to the client group as they possibly can. This is the "art" of model building, a craft perfected with training and experience. These are also the issues that we must shed light upon, to "add more science to the group model building craft" (Andersen *et al.* 1997).

In order to accomplish this, I believe modelers have to be more forthright, and externalize how it is that some "leaps" are accomplished. How was it that a particular dynamic hypothesis was crafted? How did they deal with model scope and boundary issues when conceptualizing the model with the clients? How do they balance professional and personal ethics with consultant-client relationship ethics? Where do you draw the line between loyalty to the system dynamics method, and loyalty to the client's requests and needs?

I also believe that these issues should be resolved on a case-by-case basis, with the clients aware of the tradeoffs, and engaged in the decision-making process. I speculate that awareness of the distinction between viewing the model, as a boundary-object, as opposed to a micro-world is beneficial both to the modeling and management teams. Perhaps both *pre*-intervention questionnaires (to reveal the client's expectations from the intervention) as well as *post*-intervention questionnaires (to evaluate the process used and the results achieved) should be used.

Figure 6 contains an illustration of two profiles of decision conferences. Clearly, one profile portrays a more effective intervention than does the other. But, wouldn't it be important to contrast before and after profiles? Wouldn't it be important to discuss with the clients the pre-intervention expectations, before designing and implementing the intervention? Using the CVA framework, Rohrbaugh and Eden (1990) propose the need to match the client's setting with the consultant's style and method (pp.45-47). Would it be wise to confront the client with respect to their expectations? Would it be possible (and advisable) for the modeling-team to adapt to the clients needs (or desires)?

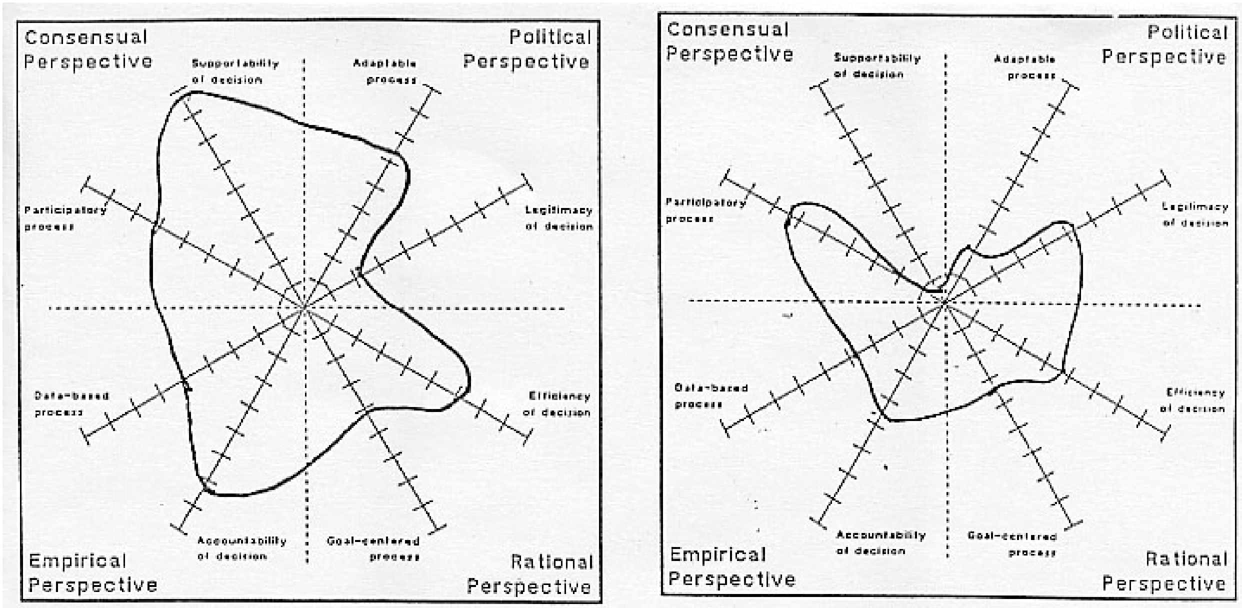

Figure 6. Two profiles of decision conferences
(Copied from Rohrbaugh 1989, pp. 126-127)

While group model building is deviating from classic system dynamics, this is neither necessarily good nor bad. It will depend upon how effectively the tension points resulting from competing values are handled. Again, borrowing from the CVA framework, I list the competing values as:

1. An adaptable process leading to a legitimate (representative) model;
2. A goal-centered process leading to an efficient (parsimonious) model;
3. A data-based process leading to an accountable (valid) model; and
4. A participatory process leading to supportability (of implementation) of model (results).

The system dynamics tradition has exercised the balance of the rational and empirical perspectives (items 2 and 3, respectively), highlighted in the micro-world view. The decision conferencing tradition has noted the importance of incorporating the political and consensual perspectives (items 1 and 4, respectively), when involving a group in a decision-making process. Existing theoretical and applied work in group model building provides evidence that the latter may be perceived as a boundary-object view of model building. Good group model building theory and practice should provide the rationale and the guidelines for making this whole package work for the client.

While the decision conferencing tradition has helped in introducing important elements to the group model building approach developed in Albany, it may have shifted the attention of the modeling team to decision-making, as opposed to policy-making. Awareness of the idiosyncrasies of group model building –the nature of its application and its theoretical foundations– will help us develop a better canon. Bringing people together, and providing them with adequate tools and proficient means to understand and work on their problems –*effective* *group model building practice*– may be just what we need to advance knowledge of social systems.

As a final note, it's worth pointing out that the concept of a "messy" problem, while key in understanding the nature of interpersonal disagreements may not be sufficient to explain the motivation behind group model building. The Albany experience has yet to be explicitly articulated. The motivation for group model building in Albany is not only related to the issue of disagreement in the client group, but also lack of knowledge of, and appreciation for, interdependencies among organizations. The fragmented nature of American government has created many opportunities and much need for integration of services, and for networking, collaboration and cooperation among government agencies and nonprofit organizations in policy-making and implementation.

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Appendices

Key references organized according to the clusters identified in the genealogy

<u>1. System dynamics</u>

Year:	Author(s):	Title:
1961	Forrester	*Industrial Dynamics*
1971-A	Forrester	*Principles of Systems*
1978-A	E. Roberts (Ed.)	*Managerial Applications of System Dynamics*
1978-B	E. Roberts	Strategies for effective implementation of complex corporate models
1978-C	E. Roberts	Some insights into implementation
1979/80	Andersen Richardson	A core curriculum in system dynamics (Toward a pedagogy of system dynamics)
1980	Legasto Forrester Lyneis (Eds.)	*System Dynamics*
1980	Bell Senge	Methods for enhancing refutability in system dynamics modeling
1980	Forrester Senge	Tests for building confidence in system dynamics models
1980	Gardiner Ford	Which policy run is best, and who says so?
1980	Graham	Parameter estimation in system dynamics modeling
1980-A	Randers (Ed.)	*Elements of the System Dynamics Method*
1980-B	Randers	Guidelines for model conceptualization
1980	Stenberg	A modeling procedure for public policy
1980	Weil	The evolution of an approach for achieving implemented results from system dynamics projects
1981	Richardson Pugh	*Introduction to System Dynamics Modeling with DYNAMO*
1983	N. Roberts Andersen Deal Garet Shaffer	*Introduction to Computer Simulation: A System Dynamics Modeling Approach*
1987-A	Forrester	Lessons from system dynamics modeling
1987-B	Forrester	14 “obvious truths”.
1992/94	Forrester	Policies, decisions, and information sources for modeling
1994	Sterman	Learning in and about complex systems
1996-A	Richardson	Definition of system dynamics
2000	Sterman	*Business Dynamics: Systems Thinking and Modeling for a Complex World*

Key references organized according to the clusters identified in the genealogy (cont.)

<u>2. Direct system dynamics modeling with clients</u>

Year:	Author(s):	Title:
1980	Stenberg	A modeling procedure for public policy
1987/97	Richmond	The Strategic Forum: from vision to strategy to operating policies and back again (aligning objectives, strategy and process)
1988/90	Vennix Gubbels Post Poppen	A structured approach to knowledge acquisition in model development; A structured approach to knowledge elicitation in conceptual model building
1989	Richardson Senge	Corporate and statewide perspectives on the liability insurance crisis
1990	Senge	*The fifth discipline: the art and practice of the learning organization*
1991	Morecroft Lane Viita	Modeling growth strategy in a biotechnology startup firm
1993	Lane	The road not taken: observing a process of issue selection and model conceptualization
1993	Winch	Consensus building in the planning process: benefits from a “hard” modeling approach
1994	Morecroft Sterman (Eds.)	*Modeling for Learning Organizations*
1994	Morecroft	Executive knowledge, models, and learning
1994	Lane	Modeling as learning: a consultancy methodology for enhancing learning in management teams
1994	Vennix Gubbels	Knowledge elicitation in conceptual model building: a case study in modeling a regional Dutch health care system
1994	Wolstenholme	A systematic approach to model creation
1994	Richardson Wolstenholme Morecroft (Eds.)	*Systems Thinkers, Systems Thinking*
1994	Forrester	System dynamics, systems thinking, and soft OR
1994	Kim Senge	Putting systems thinking into practice
1997	Cavaleri Sterman	Towards evaluation of systems thinking interventions: a case study
1998	D. Ford Sterman	Expert knowledge elicitation to improve formal and mental models
2000	Sterman	*Business Dynamics: Systems Thinking and Modeling for a Complex World*

Key references organized according to the clusters identified in the genealogy (cont.)

3. Decision conferencing

Year:	Author(s):	Title:
1979	Rohrbaugh	Improving the quality of group judgment: social judgment analysis and the delphi technique
1981	Rohrbaugh	Improving the quality of group judgment: social judgment analysis and the nominal group technique
1983	Eden Jones Sims	*Messing About in Problems: An Informal Structured Approach to their Identification and Management*
1984	Phillips	Decision support for managers
1984	Adelman	Real-time computer support for decision analysis in a group setting: another class of decision support systems
1985	Phillips	Systems for solutions
1985	Milter Rohrbaugh	Microcomputers and strategic decision making
1985	Quinn Rohrbaugh McGrath	Automated decision conferencing: how it works
1986	Phillips	Computing to consensus
1988	Phillips	People-centered group decision support systems
1989	Carper Bresnick	Strategic planning conferences
1989	McCartt Rohrbaugh	Evaluation of group decision support effectiveness: a performance study of decision conferencing
1989	Rohrbaugh	Demonstration experiments in field settings: assessing the process, not the outcome, of group decision support
1990	Eden	The unfolding nature of group decision support: two dimensions of skill
1990	Reagan Rohrbaugh	Group decision process effectiveness: a competing values approach
1991	Schuman Rohrbaugh	Decision conferencing for systems planning
1992	Rohrbaugh	Cognitive challenges and collective accomplishments
1995	McCartt Rohrbaugh	Managerial openness to change and the introduction of GDSS: explaining initial success and failure in decision conferencing

Key references organized according to the clusters identified in the genealogy (cont.)

4. System dynamics modeling used in decision conferences

Year:	Author(s):	Title:
1984	DTG	Design of a system dynamics model: the implications of a dues increase at the National Association of Social Workers
1985	DTG	Addressing alcoholism treatment program needs in New York State: a service delivery model
1987	DTG	Medical malpractice insurance: policy implications and evaluations
1989	Richardson Senge	Corporate and statewide perspectives on the liability insurance crisis
1991	Reagan-Cirincione Schuman Richardson Dorf	Decision modeling: tools for strategic thinking
2000	Rohrbaugh	The use of system dynamics in decision conferencing: implementing welfare reform in New York State

Key references organized according to the clusters identified in the genealogy (cont.)

5. Group model building

Year:	Author(s):	Title:
1988/90	Vennix Gubbels Post Poppen	A structured approach to knowledge acquisition in model development; A structured approach to knowledge elicitation in conceptual model building
1989	Richardson Vennix Andersen Rohrbaugh Wallace	Eliciting group knowledge for model-building
1990	Vennix Scheper	Modeling as organizational learning: an empirical perspective
1992/94	Vennix Andersen Richardson Rohrbaugh	Model-building for group decision support: issues and alternatives in knowledge elicitation
1992	Richardson Andersen Rohrbaugh Steinhurst	Group model building
1993	Akkermans Vennix Rouwette	Participative modelling to facilitate organizational change: a case study
1993	Vennix Scheper Willems	Group model-building: what does the client think of it?
1994	Vennix Gubbels	Knowledge elicitation in conceptual model building: a case study in modeling a regional Dutch health care system
1994	Vennix	Building consensus in strategic decision-making: insights from the process of group model building
1995	Richardson Andersen	Teamwork in group model building
1996	Vennix	*Group Model Building: Facilitating Team Learning Using System Dynamics*
1996	Vennix Akkermans Rouwette	Group model building to facilitate organizational change: an exploratory study
1997	Akkermans Vennix	Clients' opinions on group model-building: an exploratory study

Key references organized according to the clusters identified in the genealogy (cont.)

5. Group model building (continued)

Year:	Author(s):	Title:
1997	Vennix Andersen Richardson (Eds.)	Foreword: Group model building, art, and science. *Group Model Building*
1997	Andersen Richardson	Scripts for group model building
1997	Huz Andersen Richardson Boothroyd	A framework for evaluating systems thinking interventions: an experimental approach to mental health system change
1997	Andersen Richardson Vennix	Group model building: adding more science to the craft
1997	Rogers Johnson Zagonel Rohrbaugh Andersen Richardson Lee	Group model building to support welfare reform in Cortland county
1998	Allers Johnson Andersen Lee Richardson Rohrbaugh Zagonel	Group model building to support welfare reform: part II, Dutchess county
1999	Richardson	Citation for winner of the 1999 Jay Wright Forrester Award: Jac A.M. Vennix
1999	Vennix	Group model-building: tackling messy problems
1999/02	Rouwette Vennix van Mullekom	Group model-building effectiveness: a review of assessment studies
2000	Rohrbaugh	The use of system dynamics in decision conferencing: implementing welfare reform in New York State
2001	Mooy Rouwette Valk Vennix Maas	Quantification and evaluation issues in group model building: an application to human resource management transition

Table 5a. A dichotomous view of models in problem identification and definition.

The Problem

Question: How do intervenors and participants of group model building interventions view the model they are building?

Models as "micro-worlds":	Models as "boundary-objects":
Preexisting problems:	Socially constructed problems:
A model should be designed to answer a specific, tangible and meaningful question, or set of questions. (Forrester 1961, p. 449) Develop a model to solve a particular problem, not to model the system. (Sterman 2000, p. 79) A meaningful system dynamics problem is a relevant and dynamically complex problem, embedded in a feedback-rich system. (Stenberg 1980, Richardson and Pugh 1981, Reagan *et al.* 1991, Sterman 2000)	Problems are interrelated and, given multiple constituencies, there is room for ambiguity in problem selection and analysis. (Reagan *et al.* 1991, p. 52) Sometimes people will not even agree that there is a problem, much less what it is. (Vennix 1996, p. 13) Sometimes the "real" problem does not emerge until the group model-building process is underway. (Andersen *et al.* 1997, p. 194) Interrelation and ambiguity in problems adds an additional layer of complexity to already complex situations. (Vennix 1996, p. 1)

Table 5b. A dichotomous view of models in problem identification and definition.

The Purpose

Question: How do intervenors and participants of group model building interventions view the model they are building?

Models as "micro-worlds":	Models as "boundary-objects":
"The" Purpose: A systems study must be for a purpose if it is to be productive. (Forrester 1961, p. 449) A model without a purpose is like a ship without a sail. (Richardson and Pugh 1980, p. 38) The goal is to improve performance of the system. (Sterman 2000, p. 80) The main purpose of system dynamics modeling is to aid in designing better management systems. (Forrester 1961)	Multiple purposes: The purpose of the intervention is to provide a venue for negotiation and alignment to occur, adding rigor to the discussion, and providing participants with means to keep track of complex causal structures, and serving as a group memory of their understanding. (Huz *et al.* 1997, Vennix 1999) Modeling helps to create a shared perspective and understanding of the clients' issue. (Lane 1994, p. 110) In modeling messy problems, the most important goal is the creation of a shared reality and problem definition among problem owners. (Vennix 1996, p. 24) The model becomes a boundary-object in this negotiation. The model can also serve as a tool to investigate potential lines of action. (Richardson and Senge 1989, Reagan *et al.* 1991) The model-based analysis is useful if it helps the group reach a consensual decision about what to do. (Winch 1993)

Table 5c. A dichotomous view of models in problem identification and definition.

The Client/Audience

Question: How do intervenors and participants of group model building interventions view the model they are building?

Models as "micro-worlds":	Models as "boundary-objects":
A monolithic client/audience: The modeling process should be focused on the clients' needs. (Sterman 2000, p. 85) Solve a real problem that presents an opportunity perceived as important to the clients. (Roberts 1978-B, pp. 78-79) Active client involvement is essential to ensure adequacy and accuracy of model formulation with respect to reality, and to provide a basis for implementation of resulting recommended changes. (E. Roberts 1978-C, p. 156)	Stakeholders/multiple constituencies: Different people define and give shape to problems differently. Multiple constituencies using multiple criteria, and multiple resources and constraints, cause ambiguity in problem selection and analysis. (Reagan et al 1991) Stakeholders define and give shape to a socially constructed problem that emerges as an agreement from discussion and negotiation. The way the problem gets defined depends on who's in the room. Social sources of messy problems are related to deficient patterns of social interaction and communication, which fail, in and of themselves, to demystify the illusions formed in the mental models of individuals. (Vennix 1999, pp. 386 and 387) Before we can set out course to solve "real" problems, we have to struggle upon a shared understanding of what real is.

Table 6a. A dichotomous view of models in model conceptualization.
<u>The role of the structuring-framework</u>

Question: How do intervenors and participants of group model building interventions view the model they are building?

Models as "micro-worlds":	Models as "boundary-objects":
<u>The goal is to test the dynamic hypothesis</u>: The beginner usually fails to realize the importance of an initial hypothesis. There is often a feeling that to propose modes of dynamic behavior before a system model is constructed is to prejudge the answers. This is exactly what is needed. We start with a hypothesis for behavior. We build a model to see if the mode of behavior could exist and whether or not it can result from the initial assumptions. (Forrester 1961, p. 450) The goal of the conceptualization stage is to arrive at a rough conceptual model capable of addressing a relevant problem. The reference mode acts as a catalyst in the transition from general speculation about a problem to an initial model. This transition is the major creative step in modeling. (Randers 1980-B, pp. 130 and 136) The first task in formulating a model is the test of the dynamic hypothesis, which is a preliminary check to see that the basic mechanism included in the conceptual model actually reproduce the reference modes. (Randers 1980-B, pp. 130-131) Classic system dynamics advocates a *top-down approach* to model conceptualization, that seeks to conceive the key pieces of causal structure capable of reproducing key reference modes of dynamic behavior. ***(Continued in the next two pages…)***	<u>What kind of structuring-framework? How much structuring</u>? Groups are more likely to use models when it is clear to them that their ideas and knowledge is represented in the model, and when models do not seem to overly restrict team thinking. (Morecroft 1994, p. 4) People learn through discovering for themselves. People make up their own minds. (Morecroft 1994, p. 4; de Geus 1994, p. xiv) Whereas a simple list just captures items of knowledge, a framework packages and organizes knowledge. A framework also filters knowledge because some ideas won't easily fit within the constraints of the framework. So, although modelers often say that they are mapping mental models, really they are not. They are filtering and organizing from mental models to fit the modeling framework. (Morecroft 1994, pp. 9 and 11) It is important to establish which type of discussion framework will suit the client best. (Lane 1994, p. 104) Flexible approaches should be used to generate, select, and study the issues – particularly in the early stages of interventions– since these reduce any biasing of the elicitation toward system dynamics, and also allow the participants to take up the most appropriate problem structuring approach. (Lane 1993, pp. 239-240)

Table 6a. A dichotomous view of models in model conceptualization.
<u>The role of the structuring-framework</u> (continued, p. 2/3)

Models as "micro-worlds":	Models as "boundary-objects":
Decision models are intellectual tools that have been developed to make unwieldy problems more manageable by structuring thought processes, clarifying interrelationships, and handling complex data. These tools make the policy-making process more efficient by enabling policy makers to rapidly integrate and analyze information and options and make it more effective by enabling them to examine policies and their implications thoroughly. (Reagan *et al.* 1991, p. 53) System dynamics, in specific, is particularly useful in exploring and understanding endogenous causes of problematic dynamic behavior, embedded in feedback rich, complex systems. (Reagan *et al.* 1991, p. 54) The modeling team pressed for some causal feedback views but did not force an endogenous dynamic feedback view. In the end, the client team was left with few insights about the causal structure of critical parts of the system. This model-based group work might be faulted for trying to be too responsive to the group, and for failing to do a good job presenting and motivating the system dynamics approach. (Richardson and Andersen 1995, p. 133) ***(More in the next page…)***	Explaining the mysteries of system dynamics or of a particular model formulation can get in the way of uninhibited group discussion focused on the problem independent of approach or formulation. (Richardson and Andersen 1995, p. 132) Some modelers often adopt a *bottom-up approach* to model building, constructing (with the client group) a broader shared view of the system. Rather than holding a narrow focus (in model conceptualization) on the dynamic hypothesis. The modeler collects fragments of structure that, to begin with, are just lists of key resources, states and resource flows. Lists are a good way to capture manager's own categories and concepts. These lists generate raw material for an influence diagram. Wolstenholme's (1994) approach gently shapes a discussion first into a list and then into a diagram that eventually shows feedback loops, delays, and organizational boundaries. (Morecroft 1994, pp. 23-24) The most widely used reasons for creating an external representation of mental models is the great benefit that can be gained by (naturally) structuring and sharing information. (Lane 1994, p. 100) The working model serves as a boundary-object for discussion and negotiation. The final model reflects the result of the group's structuring-decisions.

Table 6a. A dichotomous view of models in model conceptualization.
<u>The role of the structuring-framework</u> (continued, p. 3/3)

Models as "micro-worlds":	Models as "boundary-objects":
	The model provides an organizing and coordinating framework, structuring the group's thinking and encouraging them to make a series of systematic decisions. The model serves as a decision accounting system. (Quinn *et al.* 1985, p. 55; Milter and Rohrbaugh 1985, p. 221) The process of model building is frequently more important then the resulting model. (Vennix and Gubbles 1994, p. 122) Different cognitive tasks require different structuring-frameworks. (Richardson *et al.* 1989, Vennix *et al.* 1992/94) A group model building intervention is composed of a repertoire of sub-frameworks, wisely used, embedded within the larger method, called system dynamics model building. An effective intervention is one that appropriately matches the series of model building tasks with the best structuring-procedures for knowledge elicitation and group dialogue. (Lane 1994, Vennix 1996, Andersen and Richardson 1997)

Table 6b. A dichotomous view of models in model conceptualization.
<u>Knowledge elicitation and mental models</u>

Question: How do intervenors and participants of group model building interventions view the model they are building?

Models as “micro-worlds”:	Models as “boundary-objects”:
<u>Eliciting prospective *theories* and *facts*</u>: Simulation models are informed by our mental models and by information gleaned from the real world. Strategies, structures, and decision rules used in the real world can be represented and tested in the virtual world of the model. (Sterman 2000, p. 88) The modeler strives toward a “mental model,” that is, an understanding of the operation of the real world. (Randers 1980-B, p. 119) A mathematical model should be based on the best information that is readily available, but the design of a model should not be postponed until all pertinent parameters have been accurately measured. In general sufficient information exists in the descriptive knowledge possessed by the active practitioners to serve the model builder in all his initial efforts. (Forester 1961, p. 58) The micro-world view of model conceptualization stresses the importance of a factual based and empirically accountable model. A good modeling process challenges the clients’ conception. Modelers have a responsibility to require clients to justify their opinions and ground their views in data. (Sterman 2000, p. 85)	<u>Eliciting *views* and *opinions*</u>: We base our models on whatever knowledge we have –real or imaginary, naïve or sophisticated. The client team may carry around quite different mental models. It is these varied models that enter the debate. (Morecroft 1994, p. 7) The group model building effort depends on the thoughts and agendas the client group brings to the workshop (Richardson and Andersen 1995, p. 133) Figure 5, copied from Morecroft (1994, p. 10) underscores the fragility of the notion that one can readily elicit theories and facts from the mental models of participants. The development of a shared mental model depends, quite literally, upon “who’s in the room.” A transitional object that is found acceptable to a group of people becomes a boundary-object that reflects the group’s negotiated representation of reality (i.e., a socially negotiated order). Often people simply don’t know how some processes function. (Vennix and Gubbles 1994, p. 138; Richardson and Andersen 1995, p. 117) Rather than eliciting people’s theories as a starting point, it may be more useful to elicit their views of the system.

Table 6c. A dichotomous view of models in model conceptualization.
<u>Delineation of model boundary</u>

Question: How do intervenors and participants of group model building interventions view the model they are building?

Models as "micro-worlds":	Models as "boundary-objects":
<u>Parsimony and dynamic hypothesis guide model boundary decisions</u>: The reference mode indicates the necessary level of aggregation and the extent of the system boundary. The modeler should select and describe the smallest set of feedback loops considered sufficient to generate the reference mode. (Randers 1980-B, p. 131) The behavior of interest must be identified before the boundary can be determined. Define the boundary that encloses the smallest number of components. Ask not if a component is merely present. Instead, ask if the behavior of interest will disappear or be improperly represented if the component is omitted. If the component can be omitted without defeating the purpose of the study, the component should be excluded and the boundary thereby made smaller. (Forrester 1975, p. 112) Without the initial hypothesis regarding the dynamic behavior under study, there is no basis for deciding what factors might be important and which ones could be neglected. (Forrester 1961, p. 450) The art of model building is knowing what to cut out, and the purpose of the model acts as the logical knife. Modelers should not automatically accede to their clients' requests to include more detail or to focus on one set of issues while ignoring others, just to keep them on board. (Sterman 2000, pp. 89 and 85)	<u>Dealing with scope and level of aggregation</u>: Some detail is justified in order to provide apparent reality and easier communication with others less skilled in model building. (Forrester 1961, p. 453) The quality of the conceptual model was increased drastically with the inclusion of more variables. Although a larger conceptual model is not necessarily better, the increase was primarily caused by refinement of the concepts and relationships in the model. (Vennix and Gubbels 1994, pp. 139-140) As models are revisited, variables are seldom dropped, it being far more likely that intermediate variables are added to clarify the nature of causality. (Lane 1994, p. 102-103) The malleability of models, and their partial fit to the mental models of participants, leads to a laundry list of concepts and variables the group wishes to see incorporated into the full model. (Richardson and Andersen 1995, p. 121) In order to put a boundary on the effects to be included, we model only one issue. We place the issue in the context of a system and then include only those aspects of the system that the *client* considers to be important or that they wish to concentrate their study on. There is no a *priori* requirement of certainty regarding quantification, or even cause and effect. (Lane 1994, p. 96)

Table 6d. A dichotomous view of models in model conceptualization.
<u>The role of the modeler/facilitator</u>

Question: How do intervenors and participants of group model building interventions view the model they are building?

Models as "micro-worlds":	Models as "boundary-objects":
The modeler as an expert in the technology; the "smart" systems thinker: The modeler brings to the group model building effort technological skills that must be exercised diligently and smartly. The modeler should view the problem and the system from the proper perspective: not too far, not too close. The modeler needs to observe first-hand the system to distinguish espoused theories from theories in use. (Forrester 1961, pp. 451 and 452) Modelers must guard against accepting the client's initial assessment of the appropriate time frame. (Sterman 2000, p. 94) A well-trained model builder can do as well as a group of model builders in tasks such as proposing formulations or designing feedback structures. Involving a group may have an apparent purpose of designing model structure, but have as a real purpose developing understanding of the system under study. (Vennix *et al.* 1992, p. 33) Modelers should not be hired guns. Modelers have ethical responsibilities. Modelers should "speak truth to power." The clients are the people the modeler must influence for his/her work to have impact. If necessary, the modeler must quit and get a better client. (Sterman 2000, p. 85)	The modeler as facilitator; the issue of ownership: A "modern" view of modeling repositions the role of the model and the modeler. Models are "owned" by policymakers, not by technical experts. They are created in a group process. The modeler is, in part, a facilitator, one who designs and leads group processes to capture team knowledge. (Morecroft and Sterman 1994, p. xvii-xviii) While the model is an intellectual tool, the process of modeling is social and political. (Reagan *et al.* 1991, p. 53) I have not met a decision-maker who is prepared to accept anybody else's model of his/her reality. "I'll make up my own mind" is pretty universal principle for everyone embracing the responsibility for his/her actions. (de Geus 1994, p. xiv) Rather than attempting to take the position, "I am an expert in techniques that will teach you about your business," the modeler should act as a facilitation consultant, offering a *process* in which the ideas of the team are brought out and examined in a clear and logical way. (Lane 1994, p. 93) ***(More in the next page…)***

Table 6d. A dichotomous view of models in model conceptualization.
The role of the modeler/facilitator (continued, p. 2/2)

Models as “micro-worlds”:	Models as “boundary-objects”:
We came to understand that the role of the modeler/reflector is more general than that of modeler and that there is great value to having a person reflecting on the group’s thinking and reflecting it back to them. The modeler/ reflector can perceive subtleties the facilitator might miss, can identify linkages and systems insights that emerge only from reflection, and can punctuate the discussion with points of important emphasis. (Richardson and Andersen 1995, p. 124)	The role of the consultant is simply to encourage clients to put forward their ideas, to clarify them if necessary, and to record them in a form that is both permanent and transferable. We use the term “articulated model.” (Lane 1994, p. 96) The modeler/reflector acts not as a master modeler but more as a reflector on the group’s discussion, a “contemplator” whose job is to refine and crystallize the thinking of the group. (Richardson and Andersen 1995, p. 124) The modeler functions as a critical outsider whose role is to ask penetrating questions, show the decision makers how to think about the problem in new ways, discover and resolve inconsistencies, and enhance the decision-makers’ emerging understanding. (Reagan *et al.* 1991, p. 55)

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