MOVING BEYOND "THE MODEL": A FRAMEWORK FOR INTEGRATING SYSTEM DYNAMICS INTO ORGANIZATIONAL POLICY MAKING

By:

Donald A. Seville

B.S., Mechanical Engineering and Science, Technology and Society
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Signature of Author ______________________________

Certified by ______________________________
Daniel H. Kim
Organizational Learning Center
Thesis Advisor

Accepted by ______________________________
Richard de Neufville
Chairman, MIT Technology and Policy Program

Accepted by ______________________________
Ain A. Sonin
Chairman, Mechanical Engineering Departmental Committee on Graduate Students

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ABSTRACT

System dynamics provides a vehicle for exploring policy questions and understanding how the dynamics of a system will play out over time. This approach enables policy makers to see the world as an interconnected whole, and to focus on the tradeoffs between the short-term and long-term consequences of a policy. Practitioners repeatedly reported that many projects, intended to introduce system dynamics into organizations, fail to result in long term adoption. This thesis explores the ways in which system dynamics can be more intentionally integrated over the long term into the policy making structures of an organization. The research for this thesis is based on interviews with system dynamics (SD) practitioners, companies that have experience with SD projects, and an in-depth case study. The results of this research are intended to increase the accessibility of system dynamics by (1) outlining some guidelines for application in organizational policy making, and (2) developing a framework with which organizations can design introduction strategies that focus on internalizing the methodology. This framework was applied to the case study company to design an integration strategy that fits their particular needs and goals.

Thesis Supervisor: Daniel H. Kim
Title: Associate Researcher, Organizational Learning Center

To my father, with love

ACKNOWLEDGEMENTS

My first thanks goes to Dan Kim, my thesis advisor, and more importantly, my mentor over the last two years. From our struggles in trying to help others put the disciplines of the learning organization into practice and in trying to live by them ourselves, I emerge a changed and hopefully better person.

Thanks to my friends in the Bose Corporation, Richard, Joe and most especially Tom, whose openness, enthusiasm, and encouragement made this research possible. Special thanks must go to their patience - now we can think about moving forward with actual implementation!!!

To Mike Radzicki, and more recently John Sterman, thank you for sparking my enthusiasm for the field - so much more than a modeling technique to me, it is a way of seeing the world and a way of living that both of them embody.

And, of course, no one can survive a thesis without extensive moral support. Thanks to the OLC group ('specially Robin, Linda, and Vicki) for their patience with my running around and boundless stress. But it was the love and friendship from my family and friends (particularly my housemates, Joe, Jonathan, Mort, Susan, and Jeff) that both carried me through the difficult times and made me remember that there were, indeed, warmer places to be than in front of the computer.

My final thanks goes to my real teacher in Organizational Learning and the ways of the corporate world, my hero, Dogbert.

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INTRODUCTION

"Today's primary threats are all endogenous, the byproducts of our own actions. There is no enemy out there to blame. As Pogo says, "We have met the enemy and they is us." Nor will blaming ourselves individually help. The causes lie in collective behaviors and unintended side effects of actions that individually make sense. There is no blame, there is no guilt, just a need to think differently."

- Peter Senge and Fred Kofman

The premise of many contemporary theses in the social sciences is to claim that the world has become increasingly complicated, leaving policy makers in ever greater need of new tools with which to facilitate policy development. The world economy *has* grown increasingly interconnected, and the speed of change is still increasing. Where once companies could count on a product being in the marketplace for 10 years, the average product lifetime is now around a year and a half. This leaves policy makers struggling to make decisions within complex, dynamic environments, primarily based on their intuition and whatever "expert" advice they can gather.

In the context of this thesis, policies are considered to be the rules by which individual decisions are made, including both the organizational and public policy realms. Two factors that make policy making difficult are: 1) the typical policy making process, and 2) the paradigm under which most policy makers operate. A typical scenario in policy making is for a group of stakeholders, with different goals and different deeply held assumptions about the way the world works, to come together because of a perceived problem and try to design a policy by consensus and compromise. One manager described the process of prioritizing new product development projects in his company as "a near random discussion." The operating assumption was that if everyone could agree on the decision, it must be the right thing to do.

The second factor complicating policy making is that the way we think and see the world can actually limit us from fully understanding problems and finding high leverage solutions. Meadows (1991) claims that some of the more limiting assumptions characterizing "western" thinking are:

- one cause produces one effect (drugs lead to crime, increased sales lead to increased profits, etc.)
- relationships are linear, non-delayed, and continuous (that we will be able to see and understand the consequence of an action)
- people are disconnected from one another
- all growth is good, and possible
- the future is to be predicted, not chosen
- a problem does not exist or it is not serious until it can be measured (made worse because we often measure what is measurable, not what is important)

Many of us, particularly from the engineering and sciences perspective, work in a problem -> solution mentality. The problem has been defined, and the thinking and work is focused on finding a solution. Often problems are even stated in solution phrasing, such as "the problem is that we don't have enough marketing." This leads us to what Kim (1993) calls a problem solving treadmill, because solutions often lead to new problems or even a re-occurrence of the same problem, after a time delay. But because it is so difficult to associate the policy solution with the new problem through all the confusion of time delays in complicated systems, we continue to apply the same solution in an endless treadmill.

To exacerbate the situation, we are trained to react to events, important "crises" that are happening now and crying out for solutions. Yet the worst of today's problems are slow, gradually emerging systemic problems such as poverty, environmental degradation, urban decay, and so on (Kofman and Senge, 1993). When one of these systemic problems has a symptomatic crisis, such as an urban riot, policy makers tend to focus on trying to solve that symptom for as long as public attention holds. Most policy makers are accountable for short term performance of the system, making it even more difficult to find the time and space to understand the long term dynamics.

Ideally, the steps to designing an effective policy would include defining the "problem", developing a shared understanding of the system in which the problem exists, designing a policy or policies to achieve the results desired, and understanding the consequences of the proposed change.

System Dynamics was founded by Jay Forrester in 1958 with the intention of improving the policy formulation process by using engineering control theory to better understand social systems. He saw an opportunity to use new advances in computer technology as a means to "test" social and economic policy before implementation, similar to the way a technological product is intensively tested before being released to the market place (Forrester, 1971).

The premise of system dynamics is that social and economic systems are high order, non-linear feedback systems (Forrester, 1964). In systems of this complexity, it is impossible to mentally simulate the behavior of the system over time - which is precisely what the policy makers are trying to do when intuitively estimating the consequences of a policy. System Dynamics provides both a language for building causal theories about systems and a computer modeling methodology for simulating the behavior of a system through time. Models developed through this methodology can allow a group of "decision makers" to build a shared understanding of the system and to see the consequences over time of proposed policies.

More fundamentally, system dynamics can assist policy makers by:

1) Compressing time and space so that the short and long term consequences of decisions can be examined. The goal is not to forecast, but rather to compare possible policies to find the most desirable one.
2) Providing insight from the modeling process. Participants in the model building process often gain enduring insight into the systemic structure that drives the daily "crisis" being faced.

1.1 RESEARCH QUESTION

Practitioners in system dynamics work primarily as facilitators and educators for teams and individuals in organizations who are trying make policy in complex environments. After helping a group of managers from the Bose Corporation build a system dynamics model to better understand their product development process, I was asked, "hey, this is pretty good stuff, what should we do next to bring it into the organization?" The company was enthusiastic enough about system dynamics to want to bring the *methodology* into their policy making process, beyond a particular issue or need. A look back into the history of the company revealed a concerted nine month effort that had been sponsored six years ago to introduce system dynamics. The effort was almost identical to the system dynamics introduction plan that I had initially envisioned, raising significant concern over how to effectively introduce system dynamics.

System dynamics, while appearing to address a deep need faced by policy makers in organizations, has remained primarily in academia and consulting. If system dynamics can be beneficial to the policy making process, then it follows that more policy makers should have the skills or access to the expertise necessary to utilize system dynamics. Further research into the question of why system dynamics has so little staying power in organizations revealed a basic recurring problem. *Introduction efforts are often not "integrated" into the business structure of the company.* Most efforts begin with a pilot project that explores a single issue and builds up system dynamics competency with internal participants. Often, however, when the consultant leaves and the initial project drive is over, there is little understanding of where and when to use system dynamics (a significant time investment) in the ongoing organizational policy making. The internal use of system dynamics slowly fades away.

The central research objective of this thesis is to examine how system dynamics can be introduced into an organization as an integrated and lasting part of the policy making process. This thesis synthesizes the experiences of several consultants, academics, and managers in introducing system dynamics. These experiences are presented as a set of guidelines for applying system dynamics in organizational policy making and a framework with which integration strategies can be designed for specific organizations. Included in this research is a case study, based on the Bose Corporation, where a tailored strategy was developed for their particular needs and environment.

1.2 CONTRIBUTION OF THESIS

Contribution To System Dynamics

Reviewing the system dynamics literature revealed considerable thought given to process concerns in system dynamics. Practitioners such as Forrester (1985), Lane (1993), Robinson (1980), Roberts (1978b), and Weil (1980) have all examined issues concerning the running of a successful system dynamics modeling project and achieving implementable results. However, no literature that I found addresses the question of why system dynamics has not been integrated into more organizations. My impression from the literature was that integration into the organization is expected to evolve naturally. A good project within an organization should generate interest and lead to other good projects, creating a reinforcing cycle. This certainly happens in some cases, but more frequently, successful projects do not necessarily lead to more applications of system dynamics.

This thesis contributes an explicit look at different experiences with introducing system dynamics and provides a framework for designing an intentional strategy. Certainly not all system dynamics projects are initiated with the objective of bringing system dynamics into the organization, nor should they be. But for the projects that have the goal of "testing" system dynamics while addressing a business issue, this thesis provides a guide for designing a strategy which specifically includes elements of how the organization will eventually internalize system dynamics.

Contribution to Technology and Policy

This thesis will contribute to the field of technology and policy by examining how a rigorous policy design methodology can be appropriately integrated into an organization. This is in contrast to the more traditional technology and policy approach, where a policy might be developed to address a specific technological issue.

Often it seems that technology policies and the techniques for designing them that are developed in academia are not successfully transferred into practice. One focus of this thesis is to learn how to best move a policy design methodology from the hands of outside "experts" directly into the practice of a company, hopefully enabling them to develop sounder policies. The system dynamics approach, used successfully, should improve the fragmented, short-term, intuitive approach that characterizes much of the current technology policy development.

1.3 OVERVIEW OF THESIS

This thesis is intended to assist people who are planning a system dynamics (SD) modeling project that has the ultimate goal of internalizing SD into their organization. The research is based primarily on three groups of interviews; consultants and academics who are system dynamics practitioners, people from companies that have had experiences with introducing system dynamics, and finally an in-depth case study of the Bose Corporation.

Chapter 2, Overview of System Dynamics, shares the general philosophy and perspective of system dynamics, the language used in the field, and the basic tools. This chapter is not intended to be a comprehensive introduction to system dynamics, but rather to show the major elements of the methodology and point the reader to good references for further investigation.

Chapter 3, Case Study Part 1, tells the story of the two most recent system dynamics introduction efforts at Bose and surfaces some key learnings. These insights have influenced the development of guidelines for the application of system dynamics and the specific integration strategy later designed for Bose.

Chapter 4, Guidelines for Applying System Dynamics to Policy Making, is based primarily on the interviews with the system dynamics (SD) practitioners and SD literature. It examines the questions of how systems dynamics can and should be used to support policy making in organizations. The research findings are structured to help answer the following questions which form the basis for designing a successful integration strategy:

- how can system dynamics be used to support policy making?
- which issues leverage the strength of this methodology?
- what does a good modeling process look like?
- what does it take to support system dynamics internally?
- what are the common ways that SD has been introduced?
- what were barriers to success encountered in the past?

Chapter 5, the Emerging Framework for Integration, presents a framework for designing strategies to integrate system dynamics into an organization's decision making structure. This framework is based mostly on the case study and other company interviews. Four major design elements emerged from the research:

- what business "role" should system dynamics play in the organization?
- based on the previous chapter, what modeling purpose or approach best suits this role?
- what infrastructure in the organization can support the long term goals of introducing system dynamics?
- what is the more appropriate short term introduction strategy?

Because most organizations have different conditions and needs, the framework is presented as a *process* so that each strategy can be tailored to that situation. Chapter 5 has two major sections. The first presents the theoretical framework for designing an integration strategy while the second section describes the strategy that was developed by applying the framework to the case study site, Bose.

Chapter 6, Conclusions, shares a brief summary of the this thesis and discusses the implications for further research.

CHAPTER 2

OVERVIEW OF SYSTEM DYNAMICS

> *"Until recently, there has been no way to estimate the behavior of social systems except by contemplation, discussion, argument, and guesswork."*
> *- Jay Forrester*

Because of the recent attention that *systems thinking* has gained through works like Senge's *The Fifth Discipline,* I will share a rough definition of systems thinking before discussing system dynamics. Systems thinking, as Senge (1990) uses the term, refers to the philosophy of seeing the whole and balancing the short-term and long-term consequences of decisions. "Systems thinking" has also been used to refer to the conceptual modeling tools of system dynamics, primarily pen and paper methods such as causal loop diagrams.

Fundamentally, system dynamics is a computer modeling technique that focuses on modeling social and economic systems. The concept of modeling social systems can cause discomfort because we find it difficult to accept the notion that our decision making can be modeled. In reality, however, all decisions are based on generalizations or abstractions about the world, what are referred to in system dynamics as mental models. The world is an incredibly complex place that we cannot carry in our heads. Instead, we develop deeply held assumptions and images of the way the world works, based on our experience and training. If we think of management as the process of converting information into action through decision making, the issue of how different people see and interpret information through their mental models is critical (Forrester, 1994). These mental models are complex, fuzzy, shifting, and often unverbalized. In the decision making process, people generally argue on high levels of abstraction, never discussing their fundamentally differing assumptions. System dynamics focuses on policies rather than decisions. A policy is a rule that states how the day to day decisions are to be made (Forrester, 1964).

In order for mental models to be communicated, we need a language. Generally speaking, words are the least helpful because of their ambiguity and inherent linearity. More effective, but also more time consuming, are mathematical models. Meadows and her colleagues (1982) characterized mental models and computer models in their work with global models:

Computer models can

- be predictive
- generate conditional forecasts
- be general frameworks
- organize many scattered pieces of information
- explicitly represent a point of view

Mental models are more often useful because they

- include rich stores of information about intangibles
- may be free of artificial barriers
- can make creative associations and analogies
- can strike a balance between incommensurable quantities and conflicting values
- are readily available, cheap and quick

Computer models may be more useful because they

- are rigorous, precise, and consistent
- are written out explicitly, can be understood and criticized
- can contain many more variables and trace interconnections
- always draw error free logical conclusions from the assumptions
- can be changed and tested quickly

However, computer models can also be so complicated that no one understands them, are frequently described in jargon, omit important but mathematically inconvenient things, and are often not tested thoroughly enough to find all the mistakes. Donella and her colleagues conclude that more can be learned from using both mental and computer models than either one alone. System dynamics rests on the strengths of each by relying on the human mind to identify and map causal relationships while using the computer's mathematical reliability to trace the behavior of the system through time. A computer simulation should not be interpreted as a prediction, but rather a statement that says *this is how the system will behave over time, based on the assumptions of the model, providing nothing else changes*. Computer simulation is seen as essential because the complexity of systems are typically beyond our cognitive ability.

Many people react to "models" as if they were the finished products, beyond alteration and refinement. In practice, each model presented is a "snapshot" in the longer evolution of the model and the theory of the social or economic system it is representing. Each question or comment leads the modeler to new questions and insights and a better model of the system. Forrester (1985) stresses that the process of modeling, more than the model itself, should be seen as a tool for improving decision making.

Sterman (1994) suggests three sets of skills as fundamental for successful systems thinking:

1) articulation - the skills to express individual mental models through facilitation tools such as feedback loop mapping
2) simulation - to model the dynamic behavior of systems and policies
3) and communication and reasoning skills - to avoid defensive routines in group modeling and learning

Good sources for learning more about system dynamics include:

- Forrester's (1971) *Counterintuitive Nature of Social Systems* for the classic introduction to the systems perspective
- Nancy Roberts' (1983) *Introduction to Computer Modeling*, Richardson and Pugh's (1981) *Introduction to System Dynamics Modeling with DYNAMO*, and the *ithink*[1] software user's manual are all excellent sources for learning modeling.

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1 *ithink* is a system dynamics software package developed by High Performance Systems; 45 Lyme Road, Hanover NH 03755, (603) 643-9636.

- Edwards Roberts' (1978a) *Managerial Applications of System Dynamics* covers some common managerial models
- and Sastry and Sterman's (1993) survey of the system dynamics literature for a broad overview of available sources

2.1 MENTAL MODELS

One characteristic of system dynamics is the use of what Forrester (1994) calls the "mental data base" along with written and numeric data. Simulation methodologies that rely exclusively on numeric data tend to leave out parameters that cannot be measured, which is effectively an assumption that the variables do not influence the system at all. In contrast, system dynamics relies on working with people who are knowledgeable about the system to estimate these variables.

A useful framework for understanding the process by which mental models are constructed is the Ladder of Inference, shown in Figure 1. This graphical framework was developed by Chris Argyris. At the bottom of the ladder is directly observable data, the things that everyone would agree to. To this data, each of us adds our own personal and cultural meaning, fitting the data into the world as we understand it. From this interpreted data, we reach generalized conclusions. For example, if someone were to walk into a meeting 15 minutes after the starting time, I would see them as late based on my expectations. I might extrapolate further, perhaps based on pervious observation, that they are always late. From such conclusions, we make inferences about the *intent* behind the action or data. "They are late because they don't care about the project, because they are so self-important." These conclusions and inferences are eventually adopted into the set of beliefs and assumptions that are our mental models.

In operation, we frequently make leaps of inference, directly from the data to our assumptions. The next time that person is late we *know* that they are always late; our previous assumptions have been confirmed. Another important dynamic is that data we see is not THE DATA in and of itself. Rather, what we see is selected based on our assumptions about what is important. There is an infinite amount of data passing us by at any given moment, and it is our mental models that provide the filters to keep out irrelevant data. For example, unless they are extreme, we rarely notice temperature, the 60 Hz background hum, or paper texture. And what we see might shift over time, depending on what we are looking for. This is called the reflexive loop, and it is why we can be blind to information that contradicts our mental models or is outside of our pervious experience.

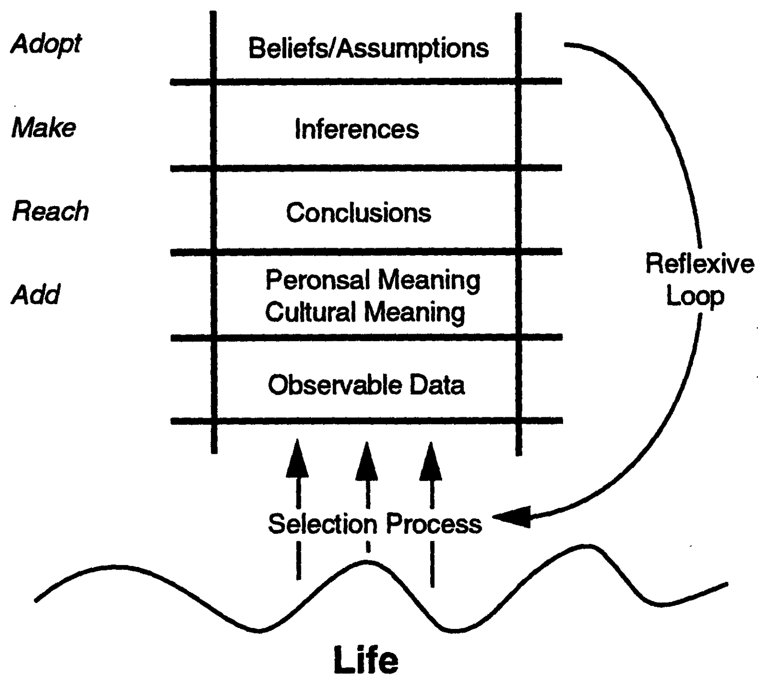

Figure 1. The Ladder of Inference (source: Issacs, 1991)

Another person might see a different set of data, leading to a different set of beliefs and assumptions. Now there are two different sets of beliefs and assumptions If discussion remains at a high level of abstraction, reaching agreement is almost impossible, particularly since the tendency in disagreements is to go up in abstraction rather than down. This discussion is not intended to suggest that mental models are negative. They are actually the mechanism that makes intuition and abstract thought possible, it would be very difficult to communicate efficiently at the level of data all the time. Leverage comes from recognizing we have mental models, which means that differing opinions are based on sets of data and experience. Operating from the premise of "if I can understand what led you to believe what you believe in, maybe I could understand it" opens up the possibility of building a shared understanding.

Part of the process of building systems thinking and system dynamics models is to build a shared causal theory. The ability to surface assumptions and the grounding data that lies behind each mental model is critical in this process. The ladder provides a tool to help each other move from the level of assumption back to the observable data. A good source for learning more about mental models is Kim's (1993) dissertation.

2.2 LEVELS OF EXPLANATION

The "system thinking" perspective will be introduced by looking at three possible levels of explanation that can be used to describe life. Each of these levels has a different realm of possible responses, and are appropriate at different times. Figure 2 shows one of Scott Adams' Dilbert cartoons that will be used as an example to see how the three levels can be used to explain a

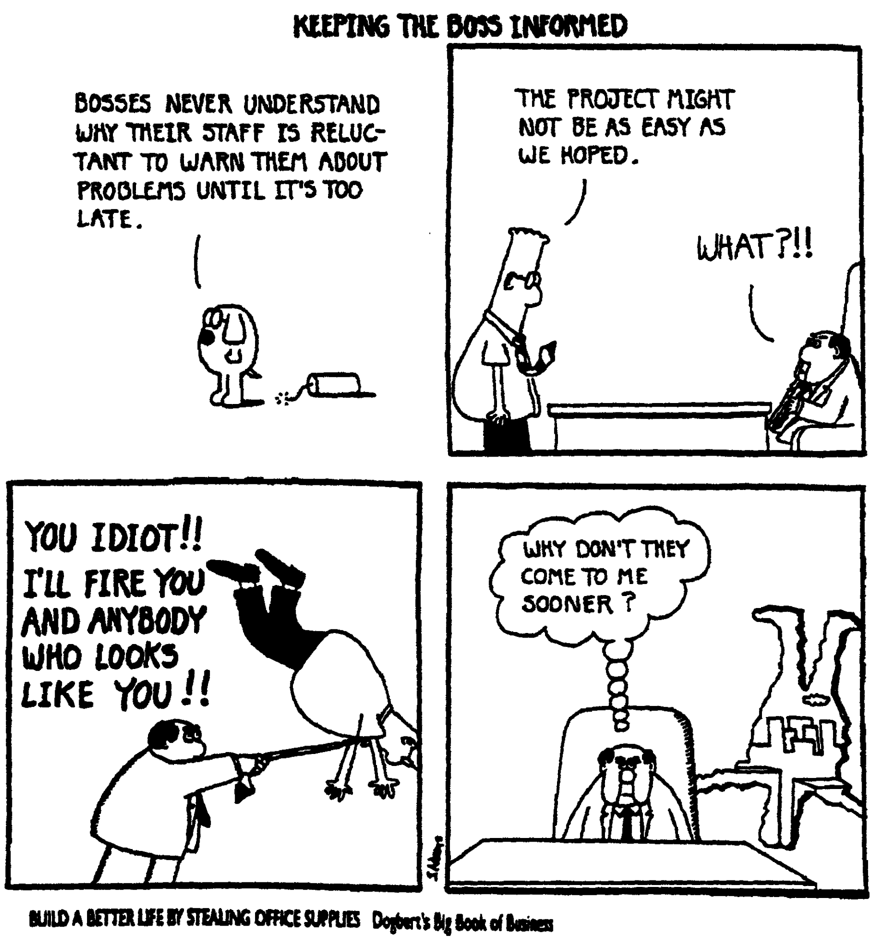

Figure 2. Keeping the Boss Informed (Adams 1991)

a situation and how we might respond differently. The levels of explanation and their associated possible responses are shown in Figure 3. The first level is events. We live in the world of events. Things happen, and we tend to *react* to them. In Dilbert's scenario, he reported bad news on his project, which caused the manager to respond with what can certainly be seen as punitive measures. And reacting to the event is entirely appropriate. The manager has to do something to try to get the project back on schedule, such as bringing in a crisis management team. But reacting to events can be a problem if we remain fixated just on events. Often it seems that people start asking what they should do about something only when events reach a crisis level. And we begin to believe that events must reach crisis level to get wider attention and action. The problem is that we are ultimately limited to simply reacting when we see the world as just events.

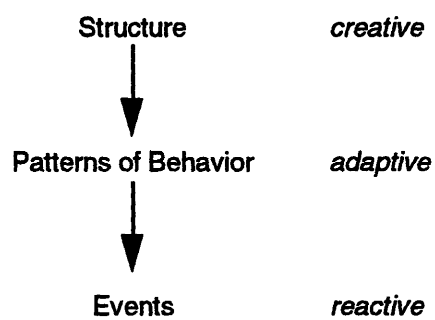

Figure 3. Levels of Explanation

There's another level, called "patterns of behavior", in which we observe events over a period of time. Certain events might recur or go up and down in patterns. The manager could notice that all of his projects wind up over schedule and over budget, and these problems get reported to him very late in the projects. He could begin to *adapt* to the pattern by having a crisis management team ready to go at the time in the project when problems typically develop. He might also adapt to Dilbert's behavior by having a trap door in front of the desk so that he does not have to destroy the wall every time. Patterns of behavior are at the level of forecast trend analysis, trying to predict the future through patterns of the past behavior. These are only accurate as long as the future behaves in the same way as the past. Even being able to predict the future does little to influence the way events happen, it would only enable us to perfectly adapt to events.

When we examine what causes the event to happen over time, we are looking at the systemic structure level. The philosophy of system dynamics rests on the belief that the behavior of a system is principally caused by the structure of the organization (Robinson, 1980). "Structure" refers to the set of physical flows, information interconnections, reward systems, habits, norms, expectations; all the things that govern physical processes and the way we make decisions. Understanding the world at this level allows us to be *creative* in our response to situations.

If our manager in the Dilbert example were to look at the situation from a systemic structure perspective, he might see the same dynamic that is shown graphically in Figure 4. The manager's punitive measures increase the reluctance of the engineers to share problems, which means that they wait as long as possible before telling. Increasing the delay in reporting problems usually means that the level of the crisis is very high by the time the manager is informed. The higher the level of crisis, the more the manager will react with punitive measures. This acts as a reinforcing feedback loop that slowly increases the magnitude of the crisis, hurting the performance of the organization.

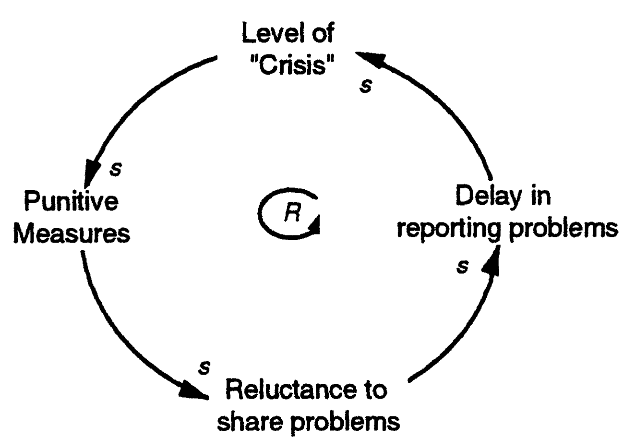

Figure 4. "Punitive Measures" Causal Loop

Seeing this dynamic from a structural level enables the manager to think about how the system can be changed to achieve more desirable behavior. In this case, he could stop punishing on the basis of the level of the crisis and instead encourage the engineers to report issues as soon as possible. Now the incentive has become minimizing the delay in reporting. Clearly, the system described in Figure 4 is a simplification of the real system. It is intended to explicitly share a theory of causation to explain the pattern of events.

The reason that we focus on systems modeling as a tool to understand complex systems is because our ability to influence events increases as we operate at the higher levels of explanation. Again, it is still important to react to events and adapt to patterns. The best management comes from the ability to operate at all three levels, and to know intuitively which operational level is most appropriate.

2.3 FEEDBACK LOOPS

The system dynamics perspective is partially based on engineering control theory, where complex systems are represented through interconnections of feedback loops. There are only two kinds of feedback loops, reinforcing and balancing (also know as positive and negative loops in engineering terms). The representation of Dilbert's dynamics shown earlier in Figure 4 was a reinforcing feedback loop. This level of modeling is called causal loop diagramming, and is a language with which to express theories of causation through a feedback perspective.

More traditional thinking tends to be linear, where we might say, A causes B which leads to C. More police lead to less crime. More sales lead to more profits. More insecticide leads to less pests. A feedback perspective would look how A causes B, which influences C, which feeds back to change A. More insecticide leads to less bugs, but it also leads to an increased rate of mutation in the bugs, leading to an increase in the population that is resistant to the insecticide, leading to more bugs in the long run.

Good causal loop diagramming helps people to elicit and portray the mental models of individuals and groups, opening them up to inquiry. Good diagramming also helps people perceive time delays, long term effects, and the multiple impacts decisions can have. The limitation of causal loop diagrams is that it quickly becomes difficult to predict how variables will behave over time or to distinguish between the strength of feedbacks loops.

Reinforcing (positive) Loops

To show a reinforcing loop, we will look at how interpersonal trust and openness of communication might be interconnected. A feedback loop relating the two is shown in Figure 5. The variables are connected by arrows to show the direction of causation. All else being equal (an assumption that nothing is changes outside these two variables), if trust increases, we would expect the openness of communication in the group to increase also. Change in the same direction is denoted with an "s". As openness of communication increases, all else being equal, we would expect trust to increase also. This is a reinforcing cycle; more trust leading to increased openness, which leads to more trust. The primary behavior of a reinforcing loop is exponential growth, such as shown in Figure 6.

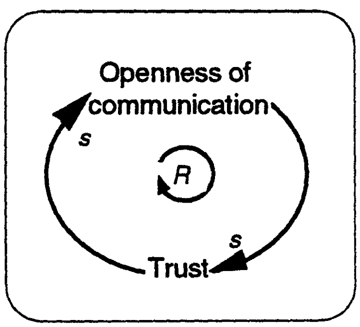

Figure 5. Reinforcing Loop

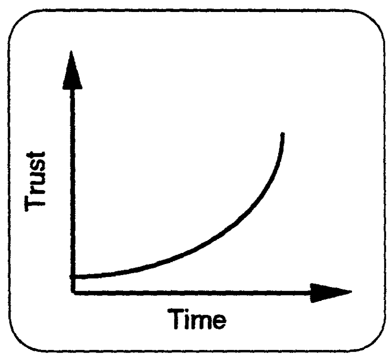

Figure 6. Exponential Growth.

This virtuous cycle can also be a vicious cycle if the loop reinforces in the opposite direction. Suppose for some reason, openness of communication went down. There would be less trust, and consequently, people would be more careful about what they say in front of each other, lowering the openness of communication still further. The feedback loop tends to reinforce in the same direction as the initial change. When we look at systems in this way, we can see that variables are not just interconnected, they actually influence each other in specific ways. Drawing this reinforcing feedback loop is a way of building and showing my theory of how trust and openness of communication might be related.

Balancing (negative) Loops

The second kind of feedback loop is a balancing loop. Balancing loops tend to stabilize things. They are usually far more prevalent in systems, but less noticeable because they do not dramatically change the system. To trace through a balancing loop, we are going to take the example of the interaction between product quality and demand of some generic product, shown in Figure 7.

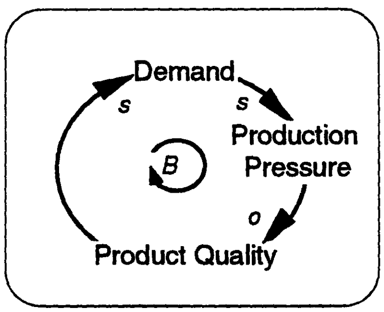

Figure 7. Balancing Loop

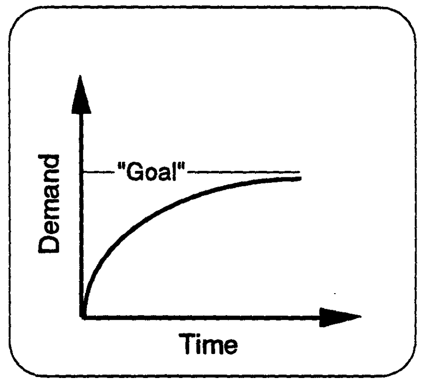

Figure 8. Goal Seeking Behavior

All else being equal, if product quality goes up we would expect demand to increase, change in the same direction. As demand increases, production pressure would eventually increase also. But if production pressure is kept up for too long, maintenance is skipped, people are overworked, and product quality will decline. Product quality moves in the *opposite* direction of production pressure, which is denoted by an "o". This is a balancing loop. Whatever change is made in one direction, the rest of the feedback structure counteracts eventually and restores the system to equilibrium. Shown in Figure 8, demand would eventually reach an equilibrium at some inherent balance, or "goal", between quality, demand, and production pressure.

For a good discussion on the limitations of causal loop diagrams, see Morecroft's (1982) *A Critical Review of Diagramming Tools* .

2.4 MODEL CONCEPTUALIZATION

Three tools used during model conceptualization are *reference modes* to define the problem, *stocks and flows* to model information and physical flows, and *causal loop diagrams* to express causal theory. Each of these concepts will be shared in a separate section. In the fall of 1993, a group of engineers from Bose worked with several MIT students to use system dynamics in exploring their systems product development process (Seville and Kim, 1993). A small portion of the Bose product development management (PDM) model will be shown to demonstrate some of what is involved in model conceptualization and computer simulation.

2.4.1 Reference Modes

A dynamic model is used to explore how things change over time. To start thinking in this mode, issues need to be conceptualized in terms of the behavior over time of important variables, called "reference modes" in system dynamics jargon. Variables, in the context of this work, are simply things that can go up or down over time. A problem in system dynamics can be thought of as an undesirable pattern of behavior. By way of example, two of the variables that were explored while developing the Bose PDM model were the project progress over time and the desired coordination between the upstream and downstream engineering groups.

The first reference mode concerns the Fraction of the Project Complete. Bose frequently experiences a very familiar product development pattern in which the first 90% of the project takes 90% of the time, and the last 10% takes another 90% of the time. The profile of the percent of a project complete for one product development group is shown in Figure 9. Since the length of the "tail" clearly impacts the time to market, the modeling team was interested in ways to reduce the tail without losing quality. This reference mode is an example of how a team might sketch their understanding of a variable's behavior. The second reference mode is Desired Coordination. The desired coordination was described as a ramping up and down around their project review date. This reference mode was used to graphically described the behavior that they wanted to see in the system.

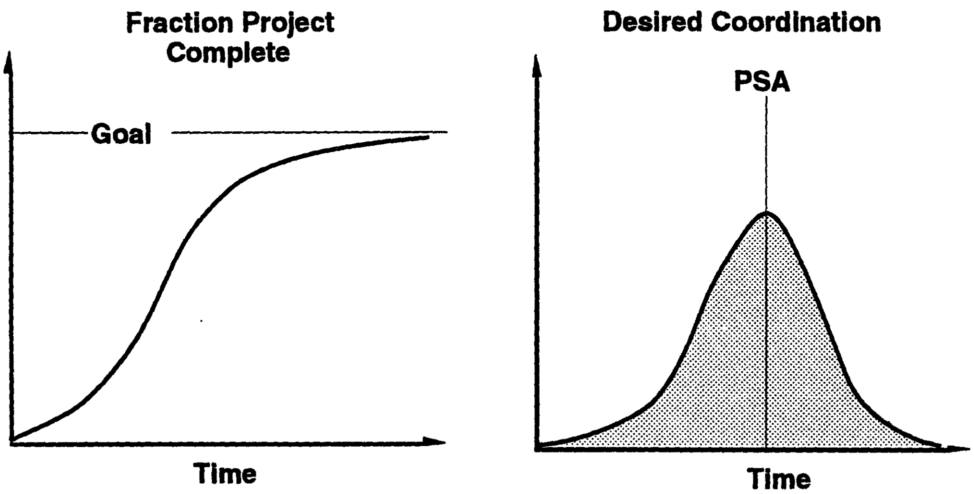

Figure 9. Reference Modes from the Bose PD Model.

2.4.2 Stock and Flow Representations

Stock and flows are the other major conceptual building block in system dynamics. They represent fundamentally different variable types that are imbedded in feedback loops. The stock and flow diagram at the heart of the Bose PDM model is shown in Figure 10. This diagram was created in a system

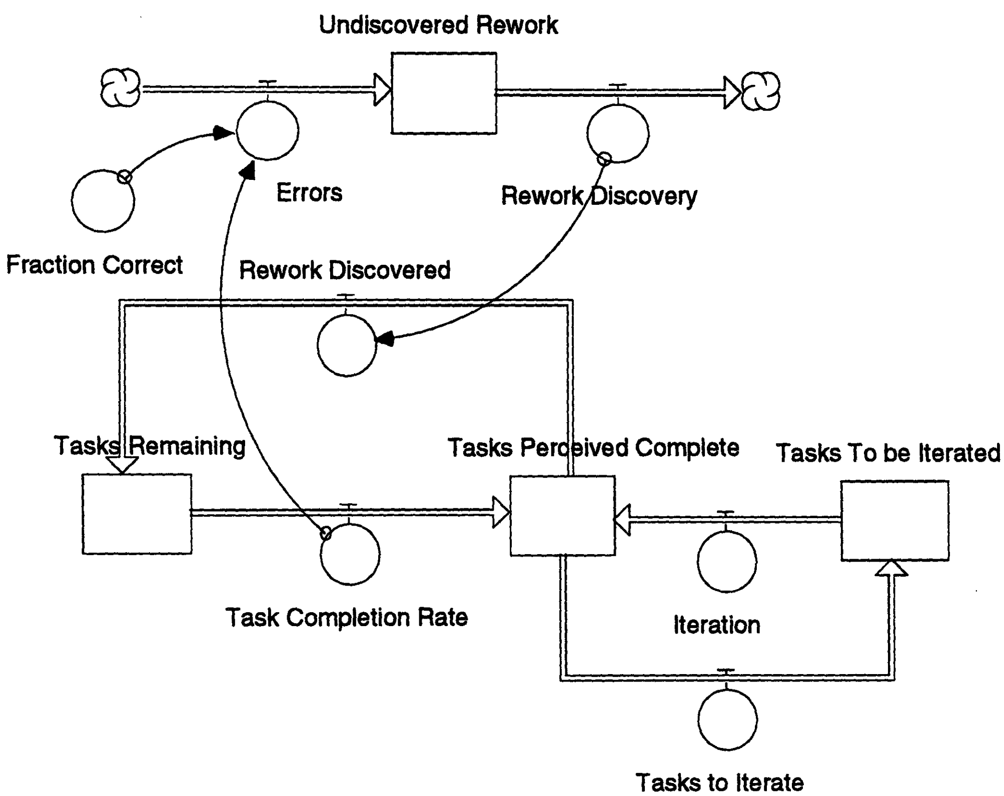

Figure 10. Primary stock and flow structure of Bose model.

dynamics modeling program called *ithink.* The rectangles in the diagram, such as "tasks remaining", represent stocks. Stocks contain "stuff" that can accumulate. Stocks will change over time as a result of flows that move "stuff" in or out of the stock. The flows are represented by the pipes with valves connecting the stocks together. The most common analogy used is that of a stock which represents a bathtub, where the flows would be the faucet and the drain. Each can change the level of water in the bathtub. In Figure 9, the stock of tasks remaining is initially full of "tasks" that must be done. The tasks are completed as a function of the tasks completion rate and flow into the stock of tasks complete. The flows are always a function of time, so the tasks completion rate would be measured in number of tasks per week. From this stock, they can either flow into the stock of tasks to be iterated or back into the stock of tasks remaining, if they are found to require rework. Stocks and flows are actually graphical representations of integration over time.

Some of the flows originate, or terminate, in clouds rather than stocks. These represent infinite sources or sinks, used when the limitations of source and disposal of whatever is flowing is irrelevant to the model. The arrows shown in the *ithink* diagram represent the passage of information and show the direction of influence. For example, the variable fraction correct is linked to the flow of errors, indicating that the fraction correct directly changes the number of errors made per week. The final icon used are the circles that are outside of the stocks and flows. These are called converters and represent constants or mathematical functions that change information outside of integration.

In Figure 10, a separate stock and flow was used for the undiscovered rework to model the dynamic of errors piling up unnoticed. When they are found (rework discovery), they flow out of the stock of undiscovered rework. At the same time, the equivalent number of tasks are removed from the stock of tasks perceived complete and moved to tasks remaining. The stock structure allows the explicit representation of the delay and uncertainly in finding errors.

2.4.3 Causal Loop Diagrams

Along with the stock and flow structure, the model team worked together to think about the relevant feedback loops. The facilitator (SD expert) worked at the board and integrated the team's thoughts into a causal loop diagram through guided questions, such as:

- what influences the number of tasks complete?
- how do you decide to iterate?
- what effects the rate at which tasks are completed?

Figure 11 shows the major feedback loops that are most closely associated with the stock and flow structure in Figure 10. Following feedback loop R1 (reinforcing loop #1), as the number of tasks completed goes up, the inherent error (a result of the natural uncertainty in the project) goes down. This increases the fraction of the tasks completed each week that are correct, thus reducing the rework required. This means that more tasks are completed than otherwise would have been. As more and more tasks are completed, it is easier to discover rework (most mistakes are found near the end of the project when all the components are brought together). Balancing

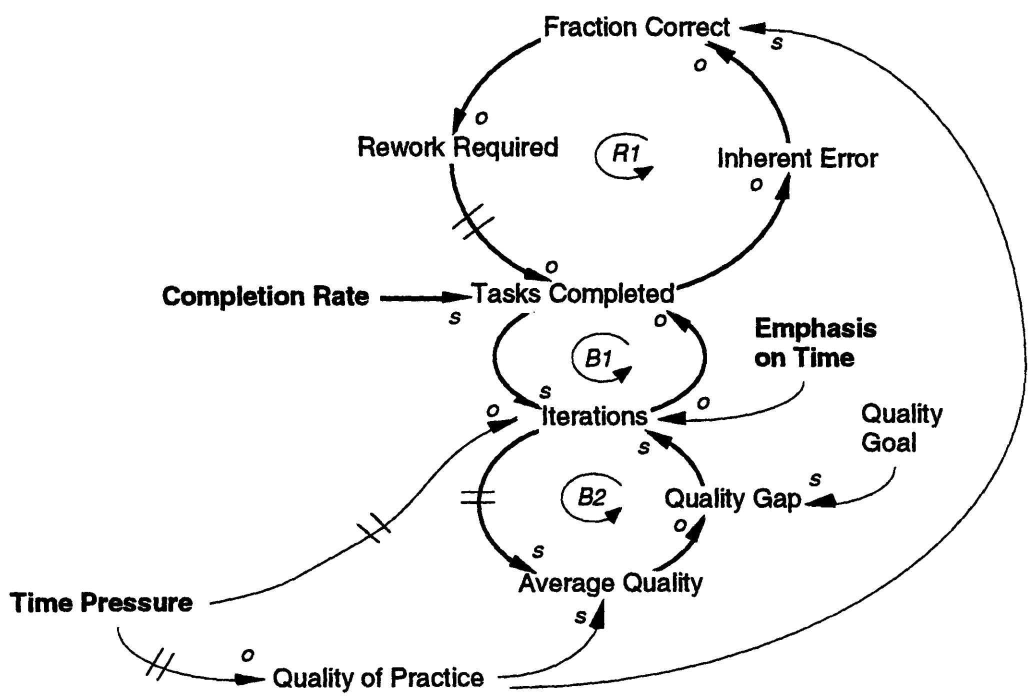

Figure 11. Bose Product Development CLD layer #1.

loop B1 shows that the more tasks are completed, the more tasks can be iterated, which in turn reduces the number of tasks available to be iterated. At any point in the project, there is an Average Quality of the product. The average quality is a function of the number of tasks completed at the current Quality of Practice, relative to the total number of tasks completed. The Quality of Practice is a measure of the current time and care being put into each task. If the quality of practice falls, the average quality will fall, increasing the "gap" between the average quality and the Quality Goal for the project. When the quality gap goes up, there is pressure to iterate more tasks , which would increase the average quality. This is a balancing loop (B2) where iterations are made to maintain the average quality at the quality goal.

2.5 SIMULATION MODELING

Even in the very simplified causal diagram of Figure 11, the behavior of the system quickly becomes difficult to predict just using intuition. Computer modeling is used to simulate the behavior of the system through time. It requires that the relationships between the variable be mathematically explicit. In the Bose project, a small modeling team took the conceptual work of the Bose engineers and translated it into a computer model. Figure 12 shows a portion of a sector of the Bose PDM model as an example. Again, the actual process of building a model is complex. This example is only intended to be a rough example.

Figure 12 is directly taken from the *ithink* modeling software. The stock and flow structure is still apparent and is integrated with reinforcing feedback loop #1 from figure 11. In the software, each of the icons can be "opened" to see the mathematical relationship that shows exactly how the modeler believes the variables are interconnected. The constants and equations in the model are either taken from actual historical data or estimated by the team. For example, the variable Fraction Project Complete is defined in the model as:

Fraction Project Complete = (Tasks_Perceived_Completed+Tasks_to_be_Iterated-Undiscovered_Rework)/Project Scope {dimensionless}

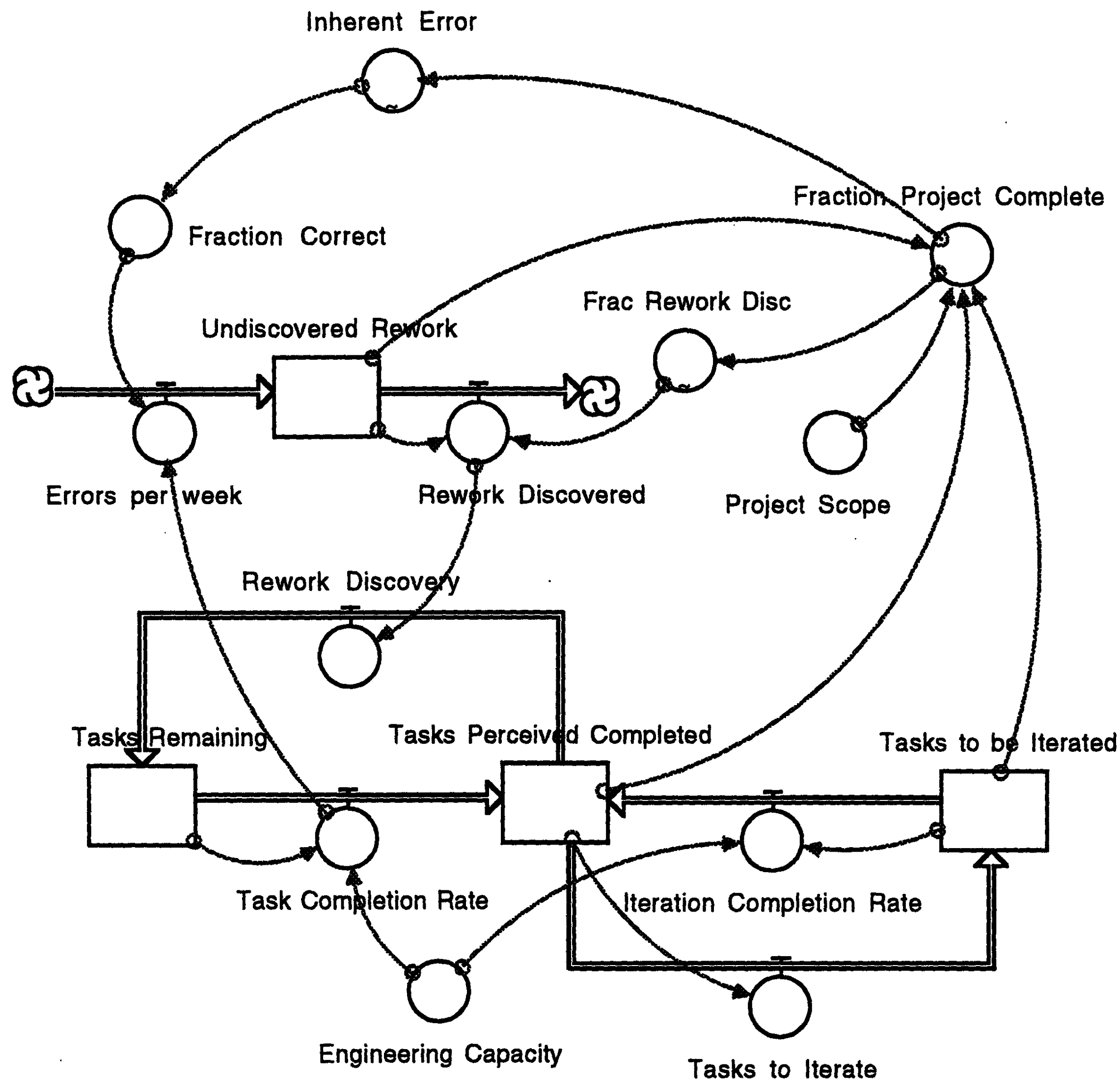

Figure 12. *ithink* diagram of a portion of the Bose PDM

Non linear relationships can be expressed through graphical functions. In this model, Inherent Error is a function of the Fraction of the Project Complete. Figure 13 shows the relationship that the modeling team decided was most realistic. The assumption represented is that the inherent error will fall to zero as the faction of project complete approaches 100%.

When all the relationships are mathematically defined, the model can be simulated forward through time to show the behavior of the system. Figure 14 shows a sample run of the Bose PDM model. The behavior over time of

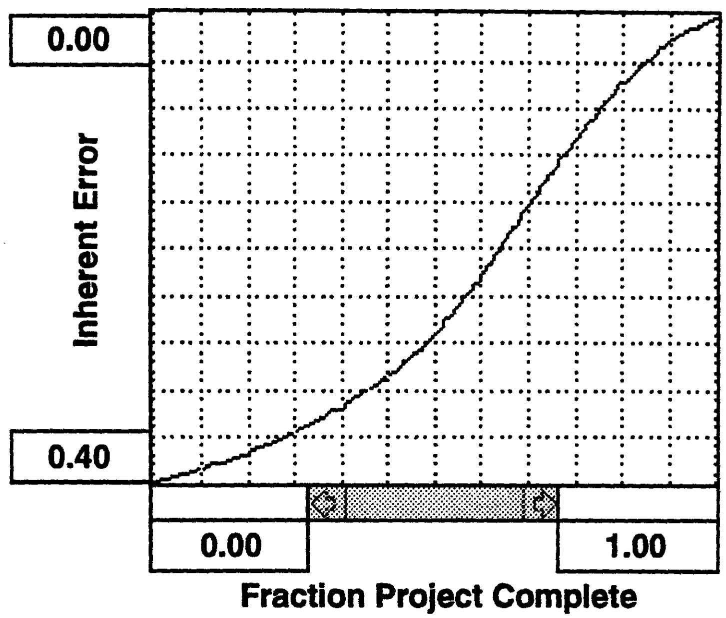

Figure 13. Graphical Function for Inherent Error

the percent Tasks Perceived Complete is shown for two different scenarios. In run #1, no iterations are allowed. Run number 2 allows iterations to take place if the average quality drops. Other graphs would show how the final quality is much higher when iterations are allowed, demonstrating a tradeoff between time and quality in this very simple model.

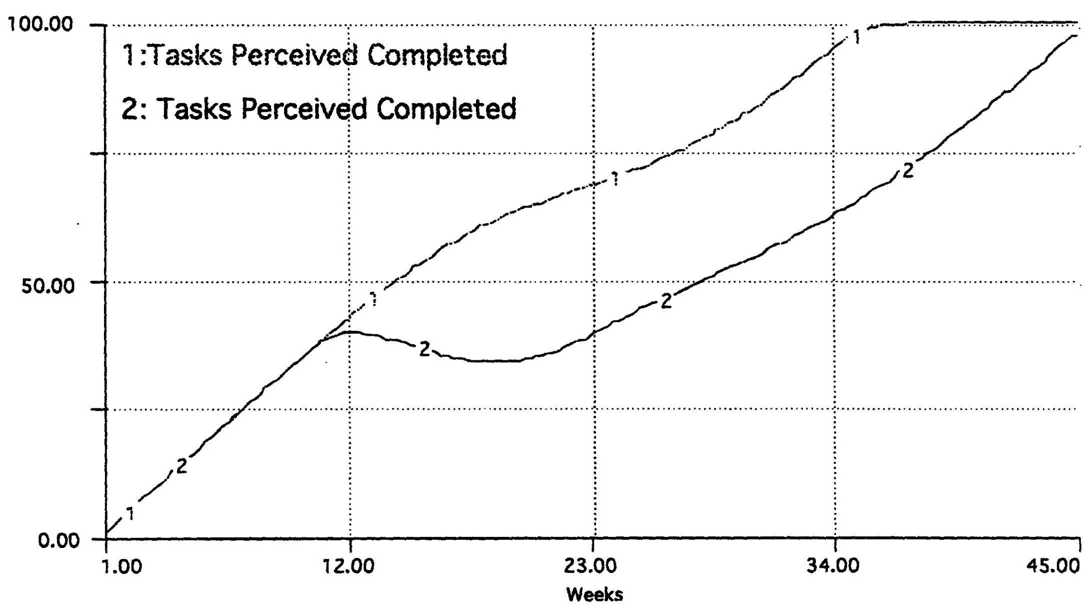

Figure 14. One modeling run from the simplified Bose PDM model

CHAPTER 3

CASE STUDY PART 1: PRIOR EXPERIENCE

The Bose Corporation of Framingham MA served as the case study site for this research. The research will be presented in two parts. This chapter will summarize the two most recent system dynamics modeling experiences at Bose and present the learnings from these experiences that are relevant to future introduction strategies. This part is presented first because it was influential in the development of the guidelines for using system dynamics and the framework for integration. The second part of the case study is presented in Chapter 5, where the framework for integration was applied to develop a specific integration strategy for Bose.

Bose was an ideal in-depth research site for three reasons. First, the president was familiar with Jay Forrester and believes strongly that system dynamics should, in an ideal world, play a role in Bose's policy making. The second reason is that Bose has had at least two significant prior experiences with system dynamics. The most recent experience was in the fall of 1993 when three students from MIT (including myself) spent a semester building a model with a cross functional product development team. Poking around the company revealed another effort to introduce system dynamics that took place in 1988. This was an extensive nine month program that was successful while the consultant was present, but the use of system dynamics faded away following the end of the consultant's involvement. The final reason that Bose was a good site for a case study is that people in Bose are currently interested in trying to bring in system dynamics based on the strategy developed in this research.

There were two distinct phases in the case study interviews. The first phase was an assessment of the previous system dynamics introductions, particularly the 1988 case, and why there was no sustained modeling. The second phase identified the most appropriate role for system dynamics within Bose and developed a strategy for integrating into the current policy making structure.

Three managers interested in seeing system dynamics brought into Bose acted as a research steering team. These managers had all participated in the most recent model building project at Bose and were interested in promoting more system dynamics projects. The research steering team met with me at least three times a month, and acted as internal champions of the project, guides for data collection, and partners for interpreting and assessing the data. A total of eleven interviews were conducted outside the steering team, including people who participated with the previous experiences, executives with a broad knowledge of the company, and other people engaged in internal process consulting work.

3.1 1988 SD PROJECT

In 1988, the then vice president of marketing asked an outside system dynamics expert, Alan Graham, to spend about a year working with Bose to "bring" system dynamics into the firm. Graham and the vice president decided that given the needs of the time, system dynamics was most applicable in the production arena. This was a time of extreme growth for Bose, and there was no separate vice president of manufacturing at the time. They put together a steering committee of 4-5 mid-level managers from manufacturing who were intended to oversee the effort. Mid-level managers were selected because this was the level of issues that the project was going to initially address. The goal was to explore issues that were important, but not urgent, and encourage the modeling group to adopt an R&D type experimental attitude.

The expectation was that the effort would last around a year, during which a sequence of different issues would be explored. The steering team identified two people as potential internal modeling experts. The in-house modelers were volunteers whose immediate supervisors were part of the steering committee. They were reported by the steering committee to be "young people", enthusiastic about the methodology. The two internal modelers were sent to a week long introduction to system dynamics course offered at MIT. Part of their formal job (and time allocation) became working with system dynamics on this project. Graham's involvement in the project was intended to ramp down over the year of the effort, as the internal modelers gained experience.

Four projects were pursued during the course of this effort. The project topics developed out of a series of data collection interviews, conducted by the steering committee, that focused on surfacing the critical issues facing the manufacturing department. Before entering the first project, the steering team was given a two day workshop that introduced both systems thinking and systems modeling. The first issue examined was Bose's policy of using temporary employees during the seasonal peaks in the manufacturing load. At the time, there was an internal debate about whether it was best to have more full time employees and try to smooth out the manufacturing peaks, or just hire temporary employees when needed. Alan led the steering team during the problem identification and model conceptualization phases of the project. One of the internal modelers took over the mathematical modeling and data collection responsibility, supported by weekly meetings with Graham. The system dynamics model suggested that it was better to have permanent employees. Based on the findings from this project, the company eliminated the temporary employee policy.

The next three projects looked at:

- incentive systems - analysis was primarily based on microeconomics and not system dynamics
- level loading in manufacturing - exploration remained at the level of facilitator guided inquiry and did not enter modeling
- delivery performance - developed a system dynamics model, but the effort was not carried through to conclusion due to lack of data

After nine months, Graham's funding for this effort expired and he moved on to a different project. The overall impression of those interviewed was that two useful system dynamics models were developed during this effort and they both led to implemented policy changes. The internal modelers continued to use system dynamics sporadically, but more for personal use than for any formal business modeling projects. They slowly stopped applying system dynamics after this point.

Reflections of the consultant

When asked why the use of system dynamics faded away after such a concentrated introduction effort, Graham offered three explanations:

- Problem identification - the new internal modelers did not have a good understanding of dynamic phenomena, and so were not able to identify problems that were most suitable for system dynamics
- No impression made on the wider organization - the introduction effort did not address the deeper critical issues, instead focusing on mid-level managers and mid-level problems
- No business role - the internal modelers did not continue modeling because there was no formal role for SD within the organization and they were not able to tie into the larger business process

Based on this experience, Graham (1989) suggested that there are 5 stages of maturing quality control in an organization,

1. initial (constant, haphazard change)
2. repeatable (doing same things the same each time)
3. defined (knowing what's done each time)
4. managed (designing what's done)
5. optimizing (using a design methodology)

He concluded that unless an organization reaches stage 3, system dynamics is a poor fit and unlikely to succeed because the problems addressed have not reached a level where system dynamics will have leverage. Moving through stage 4, however, requires a methodology like SD. He goes on to warn that using system dynamics as a complex inquiry process may be premature if a simpler scientific process like total quality is more likely to get the job done. He thought that this was the case with the problems facing Bose at that time.

Reflections of an internal modeler

The internal modeler interviewed for this thesis said she walked away from this project a positive impression of system dynamics. She continued building personal models for a while, but stopped because she perceived no demand or appreciation from the wider company. She thought that reasons for the lack of system dynamics usage included:

- no time spent on planning in the company,
- the short term focus of most people,
- the dissolution of the steering committee overseeing the system dynamics efforts,
- and the lack of corporate direction around the use of SD.

Reflections of a steering team member

One member also shared his assessment of the steering team's reaction to the project. He said the project was fun and good education, but:

- there was no commitment to the methodology - R&D "told" manufacturing to use system dynamics,
- there was no clear vision of why system dynamics should be used - most of the results agreed with people's initial intuition about the problem,
- the modeling software was seen and used more as a "spreadsheet" than a systemic feedback model,
- people returned to excel - this was more familiar and seemed to do the same things (number thinking vs. pattern thinking),
- and manufacturing moved to another location, breaking up the steering committee and the modelers.

3.2 1993 MIT-BOSE PROJECT

Bose has recently increased its product development activities from components to integrated sound systems. In response to this increase in complexity, the director of engineering, Richard Paynting, has been looking for tools and methodologies to support their management of the product development process. In the fall of 1993, Richard offered his group as a project site for the Applications of System Dynamics class taught by John Sterman at MIT. Bose sought to expose select managers to the system dynamics approach and to gain new insights into product development management based on this perspective. For the MIT class, this project was an opportunity to apply system dynamics modeling in industry. The project lasted from September through early December 1993.

Phase I. Project Initiation
The initial meetings were spent working with Richard Paynting and Tom Miller, who were the sponsors for this project. These discussions grounded the MIT students in the basics of the product development concerns facing the systems development group. The first step was to draw the boundaries of the project. The modeling effort was to focus on the product development process for systems products. In order to eliminate some of the more technically-focused and project specific portions of the new product development process, the model would focus on the portion of the process lasting from concept approval to start of production.

The MIT team decided to focus on the model building process because there was most likely not enough time in the project to build a robust, well tested model that could support true policy design and testing. Involving Bose managers in the process of building the model would surface new insights and policy possibilities during the process, rather than just from the final model. A team of Bose managers who would meet on a weekly basis for project work were selected from a variety of positions in the product development cycle to gain a wide perspective on product development (PD). The group's understanding of the PD process formed the basis of the model. The model building team was held constant in hopes of developing a shared sense of ownership over the project results. The MIT students supplemented the team meetings with outside hypothesis generation, model building, and documentation.

Phase II. Model Building
The early team meetings concentrated on defining a "problem" on which the model building process would focus. The MIT students solicited and clarified the manager's impressions of critical issues through guided discussion. The KJ[2] method was used to find major themes in the data, which emerged into three categories: the objectives of the product development process, the important concerns, and the major uncertainties. From this, the team

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[2] The KJ method is an intuitive process for sorting data developed by Kawakita (1982). Typically, data is scrubbed of judgment and put on post-its. The team then silently groups the data, based on an intuitive sense of affinity to each other rather than by logical association.

decided to focus on the role of iterations (distinct from rework) in achieving quality goals and the dynamics surrounding the upstream/downstream coordination. The model would simulate the generic Bose system product development process, specifically focusing on the role of iterations in the quality/timing arena and the interface between development groups.

One of the difficult challenges of this project was to determine how much of the core team meeting time to spend explicitly on modeling details. Because of the limited time available with the core team, the team decided to focus primarily on exploring product development issues through a loosely facilitated process. After each meeting, the MIT students would integrate the information about the PD process into the system dynamics model, and then bring the MIT interpretations back to the group for validation.

The rich discussions about product development covered more dynamics than the limited focus of the model could include. Rather than omitting the insights that were outside the boundaries of the model being developed, the MIT team collected and assessed them from the perspective of trying to understand the overall beliefs and mental models the core team seemed to have about product development. These mental model observations were used to support the modeling insights when the recommendations for product development management improvements were developed.

Phase III. Strategy for sharing the model

By the end of the modeling process, the team faced an important challenge in developing a good strategy for bringing the now complex computer model back to the core team. While the model was based on the product development issues raised during the core team meetings, most of actual computer modeling work was done back at MIT.

The goal of the system dynamics model was to provide a hands on tool with which the core team members could try out different product development management strategies to see the consequences on the overall time and quality of the simulated project. Rather than trying to introduce the entire model at once, we developed four sub-models which built up into the full model, each one increasing in complexity. These sub models were presented to the model building team in a one day tutorial. Working in pairs on *ithink,* the Bose managers built up the core stock and flow structure for themselves and then worked through several pre-prepared scenarios on each of the more complex sub-models. The core of this model was presented as the model building example in Chapter 2 of this thesis.

Throughout the process, the MIT team continued to emphasize that this system dynamics model was an explicit way to represent a set of assumptions about the product development process in Bose and simulate the behavior over time of the system under different policies, *based on that set of assumptions*. The core team and other people in Bose were encouraged to continue challenging the assumptions in the model in order to improve the model. The end product of this project was a full day tutorial, a software copy of the models used in the tutorial, and a report. The report documented the process, the model, insights from the process, and recommendations based on the work (Seville et al. 1993).

Afterthoughts on the project

Several months after the project finished, four of the Bose participants were interviewed to surface their reactions to the model and the modeling project. The interviews were intended to learn about how the project worked from the perspective of the "clients" so that the new integration strategy could take this into account. Comments from people who participated in the modeling process included that they:

- felt familiar enough with feedback loops to understand the causal loop diagrams we developed, but not enough to personally use systems thinking tools after process was over
- learned to conceptualize the product development stocks and flows as the "task buckets" used in the model
- felt enough ownership in the modeling process for the insights presented in the report to feel credible
- thought that cross function communication among the participants improved considerably
- felt the process provided a safe environment for discussion

- thought that the model directed questions from the facilitator raised issues that had never been discussed

Some reactions from people outside the modeling building team were:

- I can't see how model can be applied
- the "what if" scenario analysis is useful, but:
  - I am not real comfortable with the underpinnings of the model
  - the assumptions are not explicit (why should I trust the model)
  - there was no confirmation of model (no data)
- it is necessary to get to really know the model for scenario analysis presented in the report to be credible

3.3 LESSONS LEARNED FROM BOSE EXPERIENCE

One of the major differences between the 1988 and the 1993 experiences seemed to be that the problem explored in the 1993 case had reached the "defined stage" of Graham's five stages of maturing quality control. In this experience, the system dynamics approach was appreciated as the appropriate methodology, while in the 1988 case, the total quality tools were seen as more appropriate for addressing the problems chosen (stage two problems). Other learnings from the two experiences include:

- the lack of a business role and purpose dampened out individual efforts
- it was difficult for people who could model to recognize dynamic problems appropriate for system dynamics
- project initiative needs to come from inside the group for there to be ownership over the methodology
- the loss of the champion and expert crippled the modeling efforts
- the fact that the model agreed with people's intuition seems to have led people to trust their intuition more, not the model.
- models with no data verification were not perceived as credible
- people who were outside the model building process were more critical of the model
- people seemed to appreciate the results of having to face a problem, but do not necessarily tie the benefits of the project to the model itself
- there is little time for reflection in the daily work life, which made it difficult to continue modeling

CHAPTER 4

GUIDELINES FOR APPLYING SD IN ORGANIZATIONAL POLICY MAKING

This chapter explores the ways in which system dynamics can support organizational policy making efforts. It presents both how system dynamics has been used in the past, and also practitioners' views on how best to select a problem and run a model building project. Focusing on the methodology itself and how it shapes the possible and appropriate applications is the first half of developing a good integration strategy. Chapter 5 outlines the explicit process for designing integration strategies for individual organizations.

The first section reviews the data sources and methodology used to collect and frame data. The rest of the chapter presents the findings from the research process in a sequence of categories that have emerged as the central aspects of system dynamics that should shape integration strategies. These aspects can also be conceptualized as the questions that should be answered before designing a business role or a plan for testing and implementation.

Modeling Purposes - The section on modeling purposes presents some different ways in which system dynamics is currently being used to support policy making in organizations. There is an overlap between the different modeling purposes and the different approaches favored by various practitioners. While there are differing opinions about the strength of each approach or purpose, each can be seen as serving a distinct role within the organization and having its own requirements. These modeling purposes are by no means mutually exclusive, but having a clear vision of the one most in line with the intended business role of system dynamics is critical to designing a good introduction strategy.

Problem Selection - Like many decision making tools, system dynamics is most appropriate and useful for a certain class of problems. Section 4.3 provide a guide to the process of selecting an issue or class of issues that system dynamics is best suited to explore. Understanding good problem selection aids in designing a role for system dynamics that leverages the power of the methodology.

Modeling Process - Having selected an approach and an issue to address, the next question is what the process of modeling should be. Two aspects of modeling process are explored in this section. The first is the basic modeling steps that are fundamental to all of the different modeling purposes, though the emphasis may shift. The second aspect is how to design an "infrastructure" in an organization capable of supporting the modeling process for the long term business role intended for system dynamics.

Common Introduction Strategies - The first step of integration must be to introduce and test system dynamics. Section 4.5 describes several strategies that were used to introduce system dynamics into the organizations in the pas,t and presents the general recommendations that emerged.

Common Barriers - The final section of this chapter reviews the common barriers that introduction efforts have encountered. Being aware of these variables can improve the introduction strategy considerably. The barriers are discussed in two categories: barriers to modeling projects and barriers to diffusing the use of system dynamics from a single project.

4.1 DATA SOURCES AND METHODOLOGY

The data sources drawn upon in this research were:

- interviews with
  - practitioners
  - companies
- in-depth research at one company (case study)
  - their pervious experience with system dynamics
  - designing a strategy for future integration

- system dynamics literature
- personal experience

Practitioner Interviews

The first data source drawn upon was system dynamics practitioners who had experience in applying system dynamics to organizational policy making. Eight systems dynamics "experts" from academia and consulting were selected[3]. Each interview was a semi-structured conversation that lasted about 2 hours. Three specific questions were asked during each interview:

- Based on your experience, what do you see as the most appropriate role for system dynamics to play in an organization?
- How would you envision introducing system dynamics? Can you relate any specific examples from your experience?
- What are some of the common barriers encountered in the past that have hindered projects?

The rest of the interview questions were reactionary inquiries intended to better understand the reasoning behind different comments.

Company Interviews

To supplement the perspective of the practitioners, representatives were interviewed from four companies that have had experiences with system dynamics[4]. Each of these companies was chosen because one of the practitioners had been the primary consultant in the company's system dynamics project. This approach was intended to provide both the outside expert's and the internal client's perspective on the experience. One of the companies, Bose, was explored in depth as a case study example. For the other three, one internal person who participated in each of the projects was interviewed. The interviews with the other 3 companies were semi-structured with the following guiding questions:

- What was your experience with system dynamics?

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[3] The practitioner interviewees were Jay Forrester, Alan Graham, Jim Hines, Dave Kreutzer, Dave Peterson, Peter Senge, John Sterman, and Ed Ward.

[4] The company interviews were with representatives from Bose, Eastman Kodak, Federal Express, and Ford Motor Co.

- What happened after the preliminary modeling project? Were there other projects?
- In an ideal world, what role would seem most appropriate for system dynamics to play in your organization?
- What are the barriers that stand in the way of this vision?

The interviews were analyzed by dividing the stories told into individual "statements". The statements were then separated from the person who was telling the story. Each statement was treated as an independent piece of data. Overall common themes were identified and each piece of data was grouped according to the theme it supported. The data under each theme was then synthesized into "common opinions" and "different perspectives." The interview data presented will not be associated with specific people, with the exception of direct stories, in the interests of confidentially. Appendix A contains an example of an interview, and one of the steps in the data analysis process.

Case Study Interviews

As previously mentioned, extensive interviews were conducted with people at Bose to both understand some previous experiences with system dynamics and to design a strategy for integrating system dynamics into Bose. Bose's previous experience with system dynamics was presented in Chapter 3, and the integration strategy will be presented in Chapter 5.

System Dynamics Literature

While no papers were encountered that addressed this precise question, there is extensive literature in the system dynamics field that touches on aspects of this research. Ideas from the literature are integrated into the discussion where appropriate.

Personal Experience

The final data source drawn upon was personal experience from trying to introduce system dynamics into organizations. I have worked and studied in the field of system dynamics for the last three years, including two years with the Organizational Learning Center[5] and system dynamics modeling efforts in both corporate settings and in a town government. I gained personal insight into the role of system dynamics and some of the common barriers encountered, but I recognize that my personal perceptions also filter what I think is most appropriate.

The major themes that emerged from the practitioner, company, and case study interviews provided the structural outline, which was further developed with the addition of learnings from the literature and personal experience. The themes, presented as the sections in this chapter and in chapter 5, are modeling purposes, problem selection, modeling process, introduction strategies, common barriers, and appropriate business roles. Chapter 4 contains the general themes on modeling concerns, while Chapter 5 presents the themes centered specifically around integrating system dynamics into an organization.

4.2 MODELING PURPOSES

One of the common themes that ran through the interview data, particularly the practitioner interviews, concerned the purpose behind various modeling efforts. Six different modeling purposes that have been used in the past emerged from these interviews and from the system dynamics literature. These purposes are not intended to be presented as mutually exclusive; most system dynamics modeling projects actually have multiple goals. Articulating each purpose separately, however, allows each one to be specifically designed into the project from its inception. The purposes are:

- modeling for policy design and testing,
- modeling for learning,
- modeling for scenarios,
- modeling as a practice field for decision making,
- modeling for organizational memory,
- and modeling for corporate design.

[5] The Organizational Learning Center is a consortium of 20 organizations who are working with MIT researchers to internalize the disciplines of the "learning organization" laid out by Peter Senge in his book, *The Fifth Discipline*. Systems thinking (system dynamics) is one of the core disciplines.

Each modeling purpose will be discussed in terms of its "goal", a description of the purpose as it emerged from the data, an example where possible, and some thoughts on the advantages and disadvantages. The modeling purposes serve as a starting point for envisioning the different ways in which system dynamics can support policy making in an organization.

4.2.1 Modeling for Policy Design and Testing

The objective of Modeling for Policy Design is to develop a detailed and robust systems model that can enable explicit testing of policy options, leading ideally to the implementation of the policy exhibiting the most desirable long term and short term behavior. Specific problems are addressed and hopefully solved. While there is benefit seen in the process of building the model with a team, there is a clear vision of a "model" as the output of this process.

Primary characteristics of this modeling purpose are:

- active client involvement in focus and scope definition,
- model development through either a client modeling "team" or by consultants supported by data gathering interviews,
- requires an experienced modeler,
- tendency towards large complex models,
- emphasis on comparing results of model with historical time series,
- and continuing strategic consultation after model building phase is necessary.

Weil (1980) claims that it is NOT necessary to make disclaimers such as "system dynamics models are not developed for forecasting, they are tools for understanding problems." He feels that these kinds of models can serve both purposes, and that there can be good confidence with detailed models.

Applications of this modeling purpose include classic models such as the Urban Dynamics model (Forrester, 1969) and the World 3 model (Meadows et al, 1992). A more recent example is Sterman, Repenning, and Kofman's model of TQM dynamics (Sterman et al, 1993). For a model building process perspective, see Weil's (1980) overview of the evolution in modeling process used in this style of SD modeling.

Supporters of this purpose have suggested that it is not worthwhile to consider introducing system dynamics into an organization as a separate goal. Instead, we should remain focused on modeling substantive issues and not get distracted or diluted through training demands. Rather than provide training, these practitioners suggests that the modeling process be designed to build competency within the organization, which can then maintain the model and set up policy testing workshops.

Advantages:

- models are well tested and robust
- models are capable of detailed simulations that allow for real policies to be examined (there are many examples of companies that have saved money with this kind of model (Cooper, 1980))
- more detailed models allow for quicker policy tests than more generic models because more policy levers should already be built into the model
- detailed models can be very flexible and answer a variety of concerns
- these models can have some predictive ability

Disadvantages

- difficult to use and understand
- high value expectation
- models can cost $150,00 to $500,000 or more
- requires expertise and validation
- requires well trained people with the time available

Three of the practitioners interviewed expressed concern about encouraging organizations to become self-sufficient in this kind of modeling. They felt that while quick and dirty models can be easily made, over 90% of these are not robust and lead to more problems. A detailed model is easier to test for robustness and historical replication, and allows for more detailed policies to be developed and simulated.

4.2.2 Modeling for Learning

Four of the practitioners interviewed described a team based model building purpose that I refer to as "modeling for learning"[6]. The objective of this approach is to use the various tools of system dynamics as a facilitated process for exploring and building a shared systemic picture around an issue. In these interviews, the practitioners used the term "modeling" to include conceptual models such as causal loop diagrams along with the computer models. The distinction between this modeling purpose and modeling for policy design and testing is that this purpose does not always have a clear vision of a computer model as an end product. While computer modeling can be part modeling for learning, those practitioners advocating this modeling purpose said they only move into simulation if there are open questions and clear potential insights beyond the conceptualization phase.

Characteristics of this style include:

- team based modeling building, facilitated by modeling expert,
- focus on decision makers involvement,
- team atmosphere is research & development oriented with content focus shifting with the group's learning and questioning,
- facilitation focus is on the conceptualization phase, supported by many other facilitation tools such as KJs, Hexagons[7], and force-field[8] analysis,
- simulation models that are created tend to be small and fast,
- and less emphasis on model verification and policy testing (compared to the previous modeling purpose).

Examples of this modeling purpose in action are less common in the literature because "modeling for learning" focuses on modeling process rather than the model itself. Two examples are Lane (1993), who shows the

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6 While practitioners such as Lane (1994) and de Geus (1992) have specifically referred to a "modeling as learning" approach, the term "modeling for learning" was directly taken from the interviews. Four practitioners used this term to refer to their modeling process.

7 Hexagons are used by facilitators to capture and manipulate data during working sessions. IDON MAGNETICS LTD of Scotland is the primary manufacturer. See Hodgson's *Hexagons for Systems Thinking* for information on how they are used as a facilitation tool (Hodgson 1994).

8 A force-field analysis is a way to explicitly surface the enables and inhibitors to achieving a specific goal (Lewin 1951).

process of issue selection and model conceptualization used during an internal consulting project at Royal Dutch/Shell and Ford, Hou, and Seville's (1993), who explain a modeling process used to investigate systems product development in Bose.

The premise behind modeling for learning is that more learning occurs during the modeling process rather than in simulating the final model itself. Three of the practitioners advocating this approach said that in their experience, the majority of the learning typically occurs while exploring issues through conceptual modeling. One practitioner went on to say that causal loop diagramming is the most cost effective and most personal kind of modeling. He had found that participants in the conceptual modeling process felt like they have gotten a lot out of the process including communication, clarity of thought, and a systems perspective. His causal loop diagram modeling projects usually take from one day to several weeks of effort.

The four practitioners who have focused on this modeling purpose said that they enter computer modeling only very carefully because it can be much more expensive and the projects have a tendency to "implode" from the increased time, detail, and demand on client participation. Their stated criteria for continuing projects into computer modeling was if the "answers" couldn't be generated intuitively from the conceptual models. One practitioner estimated that 10-20% of the people in a group might not see the benefit of conceptual modeling, but over 50% will not see the use of engaging in computer modeling. He suggested that if computer modeling is done, it should be done with a smaller sub-group from the team that developed the conceptual model. The central dilemma in deciding to continue on to computer modeling appeared to be balancing the time and effort required against the possible learnings from the computer model development and simulation.

Three practitioners out of the pool of interviewees warned against modeling without computer simulation. They felt that computer simulation is *required* because no person can accurately simulate complex systems with just intuition. Any leverage points discovered during conceptual modeling are open to suspicion because of this.

4.2.3 Modeling for Scenarios

The third modeling purpose raised by two of the practitioners was modeling for scenarios. The goal, as described in the interviews and relevant literature, is to develop computer models that enable policy makers to run "what if" scenarios. The computer models are intended to be "microworlds" that capture the important feedbacks in the real system. They are not intended to be forecasting models, but rather to predict the future consequences of specific scenarios without saying which scenario will actually happen. In the microworld, policy makers can run policy experiments in a variety of possible future scenarios. The emphasis is less on the learnings from the modeling process (though these are still important) as on how the model can be used as a tool to simulate multiple possible futures and stimulate managers into thinking outside the normal bounds of the work world (de Geus, 1992). In other words, the goal is to move manager's thinking from *whether* this or that will happen to *what will we do* if this or that happens.

This methodology has the advantage of creating models that can be used to stimulate learning for people who were not directly involved in the model building process. Even so, the starting point of the scenario design **must** be the mental models of the targeted audience to build credibility into the model, or they will react badly against the "microworld" (de Geus, 1988).

The best recorded example of an institutionalized process for using system dynamics models to design scenarios for managerial learning is the Group Planning department in Royal Dutch/Shell (Heijden, 1988; Kalff, 1989). Royal Dutch/Shell is a highly decentralized multinational organization with a number of independent business units. Group Planning's mission, at the time of the articles, was to support the strategic management activities across these business units, oriented primarily towards senior management. Strategic "management" is defined by this group as:

> "... management through policies aimed at ongoing discovery and exploitation of new business opportunities, based on generalizations from specific observation and general business experience, by joint study, and consideration in a multi-functional management team (Heijden, 1988)."

Over several years of experimenting with different approaches to strategic planning, people in Group Planning made the discovery that a scenario approach was much more conducive to thinking about the fundamentals of business situations than the one-line forecasts originally used. The scenario approach was found to be more effective because it shifted the manager's focus from agreeing or disagreeing with the forecast to considering how they could plan strategically for a variety of future developments. With this change in approach, Group Planning evolved from a central strategy group to an internal consulting activity with the mission of assisting management teams to improve their approach to strategy. The internal consulting team was initially kept small, and was given five years to work with the 40 most important decision centers of the company.

An additional learning by this group was that management teams that are effective in working together are often *not* effective in long term strategic planning. Reasons include blind spots, politics, and not questioning assumptions that facilitate the day to day activity. The consulting team concluded that an effective communication process was needed.

The process developed by Group Planning to design a scenario based learning experience with decision makers includes the following steps:

Surface individual mental models
Prior to working with the team of decision makers, the consultants from Group Planning do individual open interviews designed to unearth perceptions of what is, what will be, and what ought to be.

Iterative feedback and discussion
The interviews are followed by a workshop away from the office to explore data and build shared images. Follow-up meetings are held if necessary. Often a KJ process is used to explore the data.

Provide a framework as a communication tool
The "framework" is essentially modeling. Group Planing uses five different types of "models":

1) bullet point statements

2) hexagons
3) COPE (soft-systems methodology)
4) conceptual modeling (pen and paper modeling with causal loop diagrams)
5) system dynamics computer modeling (Group Planning found that conceptual mapping in system dynamics language allows a smooth transition to computer modeling)

Group Planning added this about the computer modeling:

> "... this approach requires the precise quantification of relationships in order to develop a simulation model in the computer as a representation of mental models. Not all strategic questions lend themselves to this type of precise formulation. But if the strategy domain can be represented in this way, our experience has shown that important learning can take place (Heijden, 1988)."

Modeling is done through a combination of having managers build model parts themselves and having a facilitator build small sub models between sessions. In all instances, a successful model building process means that the managers should be able to tell if their thoughts are reflected in the model. Group planning found that in building microworlds, the forecasting ability of the model is irrelevant. They even found that in some of the most effective scenarios, the models were not built to represent reality, but rather a non-threatening similar scenario.

The final steps in Group Planning's process are to discuss the differences between opinions, scenarios, and policy experiments and to continue iterating the modeling process if necessary.

Group Planning found some of the barriers that arise in management team modeling to be:

- the time investment,
- the risks run from planning that could involve reorganization,
- and the difficulty of trying to quantify many of the policy options for the computer model.

4.2.4 Practice Field for Decision Making

Another purpose mentioned by two practitioners and a company representative was that computer simulations can also be used as microworlds where decision making can be practiced. Senge (1990) suggests that people learn most effectively through personal experience, "learning by doing". But he continues on to say that most learning by experience is actually a myth, because people often do not see the appropriate feedback (information that shows how cause and effect are related) to be able to associate what they did with the resulting consequences.

"Learning", by definition, involves doing something not already known, and often includes a period of uncertainly and risk of "failure". Kofman and Senge (1993) claim that one of the major barriers to learning in organizations is that there is very little space for risk where money and effort are riding on the results, and where is it critically important for an individual to look good. Even if an environment is conducive to new ideas and there is potential for learning by doing, people almost never directly experience the consequences of many of the most important decisions. The most critical decisions made in organizations have system wide impacts that stretch out over years, making it nearly impossible to see the feedback that cleanly links action to results. The Organizational Learning Center suggests that a "practice field" can provide an environment for learning by doing that is not otherwise possible.

Senge (1990) goes on to say that a practice field should have the following characteristics:

- Controllable pace. Time can be speeded up or slowed down to show in a few minutes the long-term consequences of decisions whose effects stretch over many months.

- Compressing space. In a practice field, the environment (system in which the decisions are being made) is reduced to a manageable size so that the consequences of decisions and actions are visible.

- Repeated trials. Sometimes "plays" must be repeated to learn what went wrong, or even to understand what variables helped lead to success.

- Pauses for reflection. To learn from doing, there must be an opportunity to sit down with the team, or with other managers, and try to understand why the system behaved the way it did in response to the strategies used.

- Safe environment to experiment. The idea of a practice field is to create a safe place to experiment with different strategies without worrying about the consequences of failure. Sometimes the greatest learnings come from failing, not succeeding.

- Appropriate tools and equipment. Without the proper environment, it is impossible to practice.

Kim (1994) sees the practice field as being one of the major components of a learning infrastructure to support ongoing organizational learning. In his vision, the practice field is continually integrated with the performance field through a learning cycle as show in Figure 15.

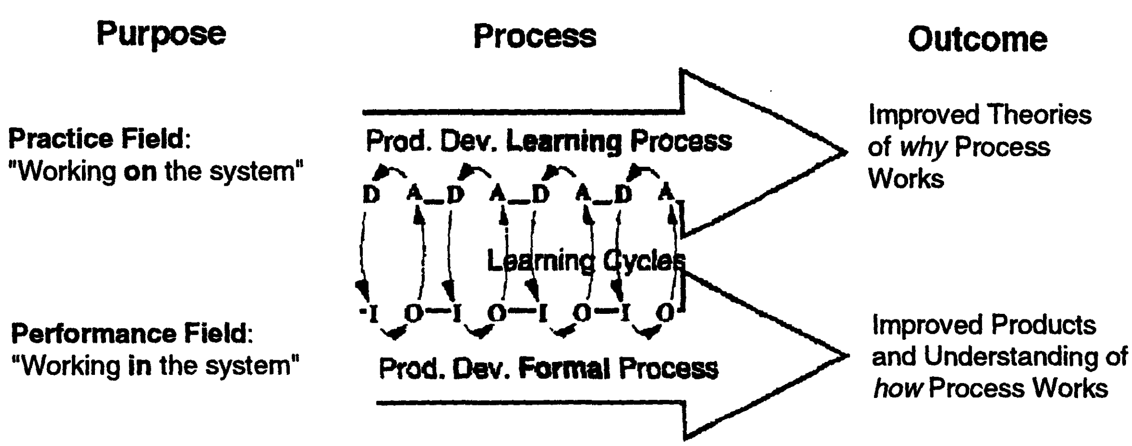

Figure 15. Practice Field and the Performance Field (Kim, 1994).

Computer simulation provides an appropriate basis for a practice field; there is no loss in failure (except pride, of course) and space and time can be compressed so that cause and effect can be better associated. Typically, an interface will be laid over the computer model to create what is called a management flight simulator. One of the key differences between flight simulators and computer models is that decisions are made each time period, placing the user of the simulator in a decision making mode, rather than setting policies in the beginning of a run of a system dynamics model.

An example of a management flight simulator designed to be a practice field is the New Product Development flight simulator used in the Ford Pilot project at the Organizational Learning Center. A full description of this simulator can be found in the Simulator Facilitator's Guide (Seville and Kim, 1993). The simulator is based on a system dynamics model of a generic product development process, similar in scope to the one at Ford. The model contains many of the key feedback loops that are present in managing any PD process. Figure 16 shows the overview report screen of this management flight simulator.

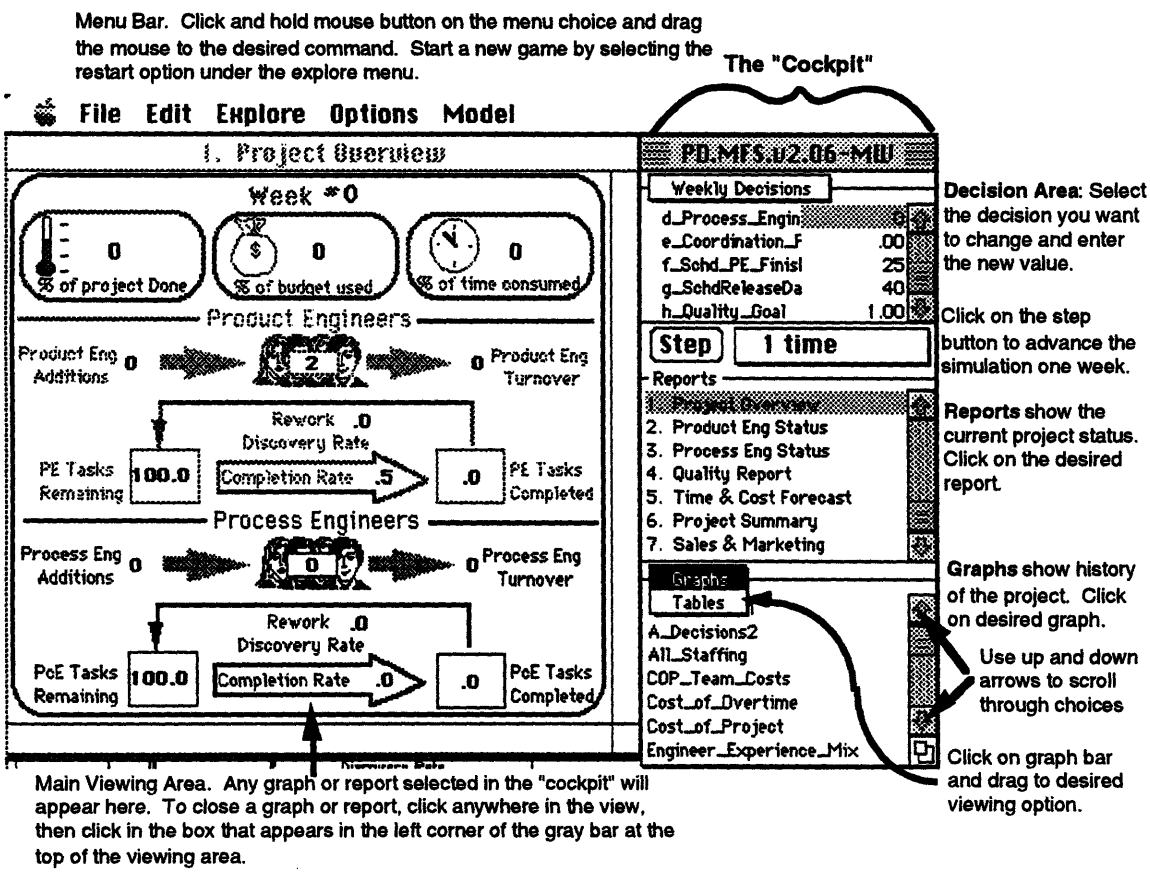

Figure 16. PD Flight Simulator Overview Report.

The flight simulator was used as a practice field in a two day "learning laboratory" at Ford. There were two kinds of practice encouraged in this session. The first practice centered on managing the product development process to learn about managing competing objectives, coordination between upstream and downstream engineering groups, and so forth. The second level of practice was in making decisions. The simulator was used in teams of two or three people, each with different experiences in product development and different views about how the process should be managed. The teams actually practiced making decisions together on the simulator, using mental model skills such as the ladder of inference and productive reasoning skills to reveal the assumptions behind different opinions. A description of the Ford Learning Lab and more information on management flight simulators can be found in *The Fifth Discipline Fieldbook* (Simon and Zeniuk, 1994).

One of first learning labs was the claims learning lab which simulated the management of an insurance claim department. The claims learning lab has been credited with (Senge and Sterman, 1991):

- shortening the learning curve for new managers
- improving communication skills
- creating an atmosphere for organizational learning
- clarifying and testing assumptions
- making mental models explicit
- integrating qualitative with quantitative measures of performance
- providing a shared experience for decision making and problem analysis

Flight simulators are one example of how a finished model can be used to spread learnings beyond the small team that was involved in the model building process. The primary difference between the scenarios and the simulator is that the focus is on experimental decision making rather than considering alternative futures. It is important to recognize that these simulators allow for experimentation instead of encouraging complex reasoning. Complex reasoning was built into the model by the team that developed it; reasoning that the player is no longer required to go through.

Such simulators have a danger of turning into black box video games and must be carefully facilitated (Sterman, 1994).

4.2.5 Modeling for Organizational Memory

System dynamics models can also support organizational memory. Kim (1993b) suggests that the parts of an organization's memory that are relevant for organizational learning are those that constitute active memory - those that define what an organization pays attention to, how it chooses to act, and what it chooses to remember from experience. These are the individual and shared mental models. Causal loop diagrams and computer models provide a way to share individual assumptions and make them explicit. By bringing their assumptions about an organization to the surface, people can work towards a coherent theory about how the organization and environment operates. In this light, conceptual and computer models can be seen as *ongoing theory building tools* (Kim, 1994b).

Modeling for organizational memory can also be seen in the context of the Lewinian Experiential Learning Model shown in Figure 17. Part of the process of modeling is the formation of abstract concepts and generalizations, which is essentially theory. The modeling process allows a group to move from observations and reflection to testing of implications while explicitly building a shared set of concepts and generalizations.

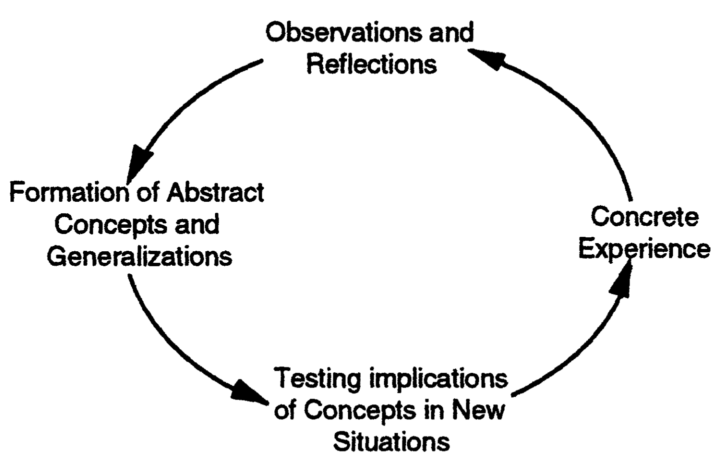

Figure 17. Lewinian Experiential Learning Model (source: Kolb 1984).

If a model is thought of as an explicit representation of a group's best current understanding of a system, then the model can be a record of that theory. The next group that is trying to understand phenomena in a similar situation can now work with the previous group's theory instead of starting from scratch. The purpose of modeling for organizational memory is to continue to refine and enrich previously developed models along with supporting the new model building processes. In practice, the idea is to continue working with the multiple models that are developed around specific questions rather than attempting to combine every dynamic in the organization into a single huge model.

Ultimately, this modeling purpose would require some group within the organization to collect and maintain models as they are developed. This group would act as a conduit between groups facing new questions and previous groups that have already developed models around similar issues.

4.2.6 Modeling for Corporate Design

Jay Forrester's original vision for the ultimate role of system dynamics in an organization is expressed in his 1965 article, *A New Corporate Design*, and enhanced by more recent interviews. He says:

> "Recent research into the nature of social systems has led to the methods of "industrial dynamics" [system dynamics] as a way to design the broad policy structure of an organization to enhance growth and stability."

Policies and decisions are conceptually quite different. Forrester (1965) defines "policies" as used in system dynamics to be the rules that guide individual day to day decisions. Creating such a policy structure, and maintaining it as conditions change and new insights are gained, would be a full time task for a small number of the most capable people in an organization. Policy making ought to be separated from the distractions of operational decision making. Otherwise the short term decision making will override the long term policy creation, which can always be postponed into the future.

Redefining the role of management:
The often quoted analogy is that moving from decision making to policy making is similar to moving from piloting an aircraft to designing an aircraft. The pilot can only operate within the limitations of the design while the designer has high leverage for change. The problem is that managers would need time, skills, and incentive to approach their jobs from a structural design perspective. This would require a redefinition of the management structure to include a team of corporate designers with the skills and mission of long term planning.

This vision would most likely be the ultimate integration of system dynamics into the organization after long successful years of trying and learning from system dynamics in other roles. During his interview, Forrester roughly estimated that a core group doing corporate design as described would take as long as 10 years to make the significant contribution to the organization's effectiveness that he envisions.

4.2.7 Summary of Modeling Purposes

The modeling purposes are summarized in two parts: the characteristics of each purpose, and the characteristics of the associated typical model developed/used. Figure 18 is a summary table that shows the three major characteristics of each of the modeling purposes discussed.

General type
The general type represents the overall type of project using a particular modeling purpose. There are two meaningful distinctions: model building and model end-use. Modeling for policy design, learning, and corporate design are approaches to building models while the other three modeling purposes are concerned with using a model after it has been developed.

Primary goal and Process focus
Defining each of the modeling purposes is a primary goal and process focus. The primary goal is central desired output of a project using a specific modeling purpose. The process focus is aspect of the process that is most critical to achieving the primary goal.

Characteristics of Modeling Purpose

Modeling for:	general type	primary goal	process focus
policy design	model building	policy	model
learning	model building	insight	modeling process
scenarios	model end-use	strategic thinking	workshops w/managers
practice field	model end-use	learning environment	learning laboratories
organizational memory	model end-use	theory building	refine and enrich models
corporate design	model building	integrated corporate modeling	policy makers as modelers

Figure 18. Summary of Modeling Purpose Characteristics.

The primary goal of modeling for policy design is to develop an implementable policy that can be designed and testing using the computer simulation. To do this, the modeling process should focus on the model itself, ensuring that the model is well-tested, reflective of the modeling team's mental model, and detailed enough to simulate actual potential policies.

The goal of modeling for learning is to surface insights during any stage of the modeling process. For this reason, the process focus is on the model building process. The facilitator should maximize the involvement of the modeling team and use the process only as long as insights are being generated.

Modeling for scenarios is an "end-use", whose objective is to use a model to stimulate strategic thinking in upper management. The process typically involves workshops where facilitators guide groups of managers in developing policies for a variety of possible simulated future scenarios.

Modeling for practice field seeks to use models in creating a "learning environment." A learning environment is a "space" where a group of managers can practice making decisions free of the risk and pressure associated with the performance field. Models and management flight simulators are usually used in multi-day learning laboratories to develop this kind of learning environment.

The objective of modeling for organizational memory is to continuously build theory about why systems in the organization behave the way that they do. The process focus is on a group in the organization who will on maintain and enrich previously developed models, while keeping important information flowing between the model and the relevant actors in each system that has been modeled.

The goal of modeling for corporate design is to integrate the model building process into the organization's management structure. This can be done by having a small group of high level managers, who are isolated from the day-to-day operational decisions, focus on using modeling to design policy. The major difference between this purpose and modeling for policy design and testing is that the managers should become the expert modelers and not be dependent on internal or external consultants.

The second way to compare the different modeling purposes is by the actual models developed. Figure 19 shows the characteristics of "typical" models developed or used for each purpose. Each of the characteristics is rated on a relative high/low scale based on my assessments of the research data. Because modeling for organizational memory and corporate design will include a wide variety of models, no judgment is placed on most of the model characteristics (NA - not applicable). There are three characteristics used:

- Emphasis on realism - the emphasis placed on the model building to represent the "real world" as closely as possible.
- Investment required - the time and effort usually associated with this kind of model.
- Detail of model - a judgment of the size and detail commonly associated with each model type.

Typical Characteristics of Model

Modeling for:	emphasis on "realism"	detail of model	investment required
policy design	Hi	Hi	Hi
learning	Lo	Lo	Lo
scenarios	Hi	Hi	Hi
practice field	Lo	Lo	Hi
organizational memory	NA	NA	Hi
corporate design	NA	NA	Hi

Figure 19. Summary of Typical Model Characteristics.

Two trends are readily evident. The first is that modeling for policy design and modeling for scenarios have the same model characteristics, indicating that using modeling for policy design to develop the model used in scenario workshops is extremely appropriate. Similarly, modeling for learning and modeling for practice fields are mutually supportive. Modeling for practice fields has a higher investment required because it includes an additional modeling stage to design and test the interface of the management flight simulator.

The defining characteristics summarized in Figures 18 and 19 represent a rough description of a common modeling project following each of these purposes. Actual projects will, of course, vary considerably with the style of the facilitator/modeler and the desires of the modeling team.

4.3 APPROPRIATE QUESTIONS FOR SD

A strong theme that ran through the interviews with the practitioners was the need to know when system dynamics is the appropriate methodology for exploring an issue. Because of its nature, and because of the time investment required for most modeling efforts, system dynamics is not a tool for all decisions. Three of the practitioners and one of the company representatives said that one of the most critical skills (and one that takes the longest to actually develop) is the ability to recognize problems that are suited for system dynamics. Problem selection is important in two steps. First, one must decide if system dynamics is appropriate for the issue being examined. If so, it is next critical to focus the exploration on a problem within the larger issue, rather attempting to model an entire system. As every system dynamistic has heard many times, *model a problem, not a system.*

Forrester himself is very clear about the limitations of the technique. He states that system dynamics is not appropriate for (Forrester, 1986):

- problems that lack systemic interrelationships
- areas where the past does not influence the future
- situations where changes over time are not of interest

Clearly, there are going to be differences in problem selection based on the role of the modeling in the organization. But even when the issues has been identified, there is usually flexibility in defining the exact focus. Defining a problem that plays to the strengths of system dynamics increases the probability of developing a good model with implementable insights. The next section outlines the important problem selection criteria that emerged from the practitioner interviews.

4.3.1 Project Selection Criteria

Dynamic Complexity

System Dynamics, as the name suggests, is fundamentally oriented towards examining dynamic behavior. Causal loop diagrams and computer models are really dynamic hypotheses, causal theories about why things change over time the way they do. A reference modes (graph over time) is the basic tool in SD for defining a problem and it is intended to show the behavior over time that is of concern and needs to be causally explained. When change over time is not a concern, system dynamics is not appropriate.

There is an important distinction between dynamic complexity and detail complexity. Detail complexity is found when there are many interconnected elements to a system, making it difficult to conceptualize the large network of interrelationships. Dynamic complexity exists when it is difficult to predict how the system will behave over time. Feedback systems can be thought of as multi-order non-linear differential equations where the dominate feedback loops often shift over time.

Detail and dynamic complexity are often unrelated. The greater the dynamic complexity, the more appropriate it becomes to use computer simulation to understand how and why the system will change over time. This will help locate "leverage" points within the system (Kim, 1993). It is in the dynamically complex arenas that mental models tend to be systematically deficient (Bakken, 1993; Diehl, 1992; Sterman, 1989). The model building process provides a vehicle for challenging and improving these mental models.

A sign of dynamic complexity is when the dynamics caused by a change in the system unfold over a long time period and/or when there are consequences across the organization. If cause and effect are closely related in time and space (consequences are here and now, such as in many manufacturing defects), it is probably more appropriate to do real life experiments and alter the policy until the best solution is found.

Generic vs specific model

In choosing a problem, there is a delicate balance in defining the specificity of the problem. Models should address real issues and not just generic processes (Roberts, 1978b). Addressing a specific problem is critical to getting the data and understanding necessary to test the model being developed. But the most leverage comes from exploring problems that reoccur for the organization, where the understanding of the system can be generalized from the specific problem to the general problem type. Thus it is productive to avoid exploring issues that have only one time impact, selecting instead a level of abstraction on reoccurring issues such that the "forest doesn't get lost because of the trees...."

Importance to company

Exploring an issue through system dynamics requires an investment of time and money. The problem being examined should be important enough to justify the investment of time and energy spent trying to get a full understanding and the best solution, not just on a cost-benefit analysis basis, but also on the emotional level. Participants in the modeling process should feel energized about the problem and willingly spend time on the project, taking it seriously enough fully engage in the process. Important issues are typically places where potential payoffs are high. However, there is danger from looking at urgent issues, particularly early in the life of system dynamics in an organization, because the pressure on urgent issues makes it difficult to step back from a problem-solution focus to take an unbiased learning approach. It has been suggested that the best problems are problems that are important but not urgent.

Time Available

Good modeling efforts require time. If the company has to make a decision about an issue immediately, system dynamics is not appropriate (though systems thinking is still useful). Recalling the levels of explanation discussed in Chapter 2, system dynamics should not be used to react to something at the event level. In other words, modeling is less useful in understanding the decisions being made tomorrow than it is in comprehending the ingrained patterns and structures which drive how the decision is being made.

Credibility

The objectives of the model building process should be credible, both in the eyes of the participants and in the wider organization (Roberts, 1978). One way of increasing the credibility is to look for problems that have some measurable variables associated with them, tying the modeling into grounded data. Again, this is most important when the organization is first gaining experience with system dynamics.

Knowledge of system

One senior executive who was interviewed suggested that there were two classes of decisions being addressed at the strategic level in his company.

1) Incremental - deciding to do more or less of the same policy options that have been used in the past. These kinds of decision are changes in pricing, marketing, employee head count, etc. This executive felt that the long term consequences of this kind of decision would be possible to model because much of the system and its behavior are known.
2) Breakthrough decisions - deciding to break into new areas where the company has no previous experience, such as moving into a new market areas. In the experience of this executive, these decisions are made based on instinct and would be difficult or impossible to credibly model.

First Project Consideration
Selecting a good first project while introducing system dynamics to an organization is even more critical. As always, people's feelings towards a new tool are heavily colored by their first impression. The above criteria still hold, but some additional guidelines for selecting a problem are -

- high potential leverage, start with areas where there is previous theory to build on
- R&D attitude, expect learning experience, not immediate solutions for pre-defined problems
- select a problem that should lead to an easy success, but not so trivial that system dynamics adds no new insights (if people would have come up with the same answer through intuition, they will not see the need for the modeling)
- issue should be important, but definitely not urgent

The general hope is that a successful first project will attract attention and desire to apply SD elsewhere in the system. This will be discussed further in the section on introduction strategies.

4.4 THE MODELING PROCESS

We have now examined general modeling approaches and appropriate problem selection. This section covers the general process that should be used in building system dynamics models. This process was developed by synthesizing and generalizing personal approaches described by practitioners and one of the company representatives. There are two primary concerns in the modeling process question. The first concern is, what is a good model building process to explore a single issue? The second concern is, how can an internal support system, what the Organizational Learning Center refers to as an "infrastructure," be developed to support on-going modeling initiatives?

Again, the specific design of each project and the system dynamics infrastructure depends on the modeling purpose, the specific projects, and the overall business role that SD is intended to play. In this discussion, I am going to assume that the guiding principles of the modeling project are to:

- build the best model possible,
- maximize learnings of those involved in the modeling process,
- and maximize the chance that insights can be implemented.

Although the focus in this section is how to support team based modeling, it certainly is not intended to discourage individual modeling. The reason for focusing on team modeling is that most important decisions made in organizations are now made in teams. Learning together as a team vastly increases the chances of any insights being implemented.

4.4.1 Exploring an Issue through System Dynamics

Sterman and Senge (1991) have conceptualized the overall modeling process in three learning stages:

1) mapping mental models[9]
2) challenging mental models
3) improving mental models

The nine phase modeling process proposed in this section is intended to provide a framework for these learning stages with the additional intent of achieving implementable model based policy suggestions (personal mental model improvements might not necessarily lead to systemic changes by themselves). Sterman and Senge (1991) claim that the most important result of the mapping process is to uncover critical assumptions and set the stage for challenging them. The mapping stage is generally the pre-model

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9 See Chapter 2, Overview of System Dynamics, for a discussion of Mental Models.

conceptualization work, such as causal loop diagramming, while the simulation modeling provides the engine for challenging assumptions. To be effective in challenging mental models, teams must have high ownership in models. While models developed and interpreted by outside experts may change what managers think about a particular issue, they rarely change the way managers think about future issues. In contrast, the model builder often acquires enduring insight (Sterman, 1994).

For example, one result of my own effort to lead a team in building a system dynamics model of Bose's product development process is that the Bose team members can now conceptualize and discuss their process in terms of the stock and flow structure they helped develop.

Model Development Phases

The nine phases are (1) project initiation, (2) initial data collection, (3) developing the model building team, (4) preliminary training, (5) problem definition, (6) systems conceptualization, (7) model formulation, (8) model testing and evaluation, and finally (9) policy experimentation. In practice, these steps are not always linear and will evolve with the specific needs and goals of a project. They are intended to give shape to the overall concept of what the modeling project should look like. There are very rough time estimates given for each phase, except for the first three which are the difficult to predict "project definition" steps.

A detailed example of a model building process in the modeling as learning style is described in Lane's (1993) paper, *The Road Not Taken: Observing a process of issue selection and model conceptualization.*

1. Project initiation

The initiation phase of a project usually involves a project champion, the sponsor, who is interested in exploring a particular issue or in testing out system dynamics as a methodology. Typically this champion will seek out a system dynamics "expert", either an outside consultant or inside practitioner, and together they will define the initial steps. Important in the project initiation is to consider what the overall objectives of using system dynamics are and to develop the most compatible modeling purpose. These objectives may shift over time, but having an initial explicit vision of the desired outcome can be a significant success factor.

The role of the SD expert is to be the facilitator for the model building process and pull out the pertinent information to map mental models. Having a vision of the full process allows the guiding steps to be more explicit. An internal person can certainly play this role, but this person would need the skills and perspective to ask the right questions, and they might be encumbered by political baggage.

The interviews with representatives from companies with system dynamics experience emphasized the importance of working with an outside consultant as facilitator, at least until system dynamics expertise and credibility has been established. This is both for reasons of expertise and because companies generally allow themselves to be guided by an "expert" where an internal person would not have the credibility to introduce a new tool into the organization.

2. Collect initial data

Although most projects are initiated with a specific problem in mind, it is important to collect some data around the perceived critical issues before launching into the modeling process. Typically this is done through interviews with people representing different perspectives on the problem. This sets up an initial data base for the modeling team to work with and also helps reveal who the critical players are that should be represented in the model building team.

3. Develop the modeling team

As mentioned before, a modeling team is desirable both because most decisions are made by groups and because it increases chances that a rich mental model base will be incorporated into the model. Selecting an appropriate team is critical for developing shared ownership and cross-functional insights that can facilitate implementation of results.

Ideally, a project team consists of people representing various perspectives on the issue being explored. The ideal team should have the following characteristics:

- an intuitive appreciation of dynamic complexity,
- a willingness to invest the time to learn,
- a commitment to fundamental change,
- an understand that systemic change requires personal change,
- the power to take action, or trusted by those with the power,
- and credibility within the organization (diffusion potential).

In a facilitator led process, a good team size would be four to five committed participants with a maximum of eight people. Preferably two people active in the modeling or interested in being modelers, and two to three people knowledgeable about the content of the issue. During the computer modeling phase, three to four real participants are optimal: four to work at the conceptual level, but only two people developing the actual equations, is generally the most effective dispersion of people.

The champion serves as the initial driver for "solving the problem" while the facilitator is the guardian of the process. Establishing expectations with the team is also an important upfront step (Robinson, 1980). An initial goal, time frame, and foundations (ground rules) should be developed. Practitioners emphasize that a particularly important expectation is a shared understanding of the research and development nature of model building projects. Many of the insights generated might not directly relate to the "problem" itself and the group should be able to learn from these also.

4. Preliminary training

Since systems thinking is an unfamiliar perspective for most people, the team should be grounded in the basics of systems thinking and system dynamics before launching into the process. It is NOT necessary that people be intimate with the computer modeling, but it is important that they be familiar with the language and concepts that will guide the first couple of phases of the project. The details of computer modeling can be learned through doing.

A good strategy is to kick off the project with a two day workshop that introduces:

- mental models (perhaps LH/RH column and ladder of inference)
- causal loop diagramming
- stocks and flows
- computer modeling as a natural extension to conceptual modeling (not as a separate endeavor)

The goal is not to train everyone to be system dynamicists, but rather to enable the team to share the same language before embarking on the project. These kind of workshops should not be isolated training exercises. The issue that the team is going to address can serve as the content area for the practice session, providing grounding in the issue and methodology before getting deeply into the model building.

5. Problem definition - approx. 2 sessions (once/week)
The problem definition phase is an important time to step back from the initial problem declaration to begin thinking dynamically about the issue and to try re-articulating the problem from multiple perspectives. This phase typically is characterized by:

- divergent thinking
- defining and prioritizing key issues
- estimating reference mode behavior
- defining overall objectives for the modeling project

The previously gathered data can serve as a starting point for discussing the issues. Methods such as force-field analysis, hexagons, and KJs (also known as affinity diagrams) are very helpful for analyzing and organizing data.

6. Conceptualization - approx. 6 sessions (once/week)
The role of the facilitation is to capture key relationships and delays by using causal loop diagrams and stock and flow representations. Causal loop diagrams are a way to express causal theories intended to explain the behavior of the reference modes. This phase includes:

- exploring the business issue
- identifying feedback (reinforcing/balancing)
- developing causal loop diagrams
- mental simulation of the behavior of the system mapped
- defining boundaries to the system

7. Model formulation - typically a 4-8 week process
As previously mentioned, there is a range of opinion about when it is appropriate to continue from conceptual to computer modeling. Some feel that because the human mind cannot simulate causal loop diagrams through time reliably, conclusions drawn from just conceptual models are not well grounded. Others believe that due to the time and investment required to build a good model, projects should only proceed when there is clear additional learning to be gained (high dynamic complexity).

The computer modeling phase animates feedback loops (dynamic behavior) to examine delays, magnitudes, and dominance of loops. This explicitly tests out the theories laid out in the conceptualization phase to see if they can produce the behavior expected.

The conceptualization phase can lead to computer modeling by asking the question of how the "system" sketched out by the group will behave over time. It is critical to mix in mental simulation with the computer simulation (i.e. have the group try to sketch how they think the system will behave over time) to show possible deficiencies in mental models and the difficulties of estimating behavior over time in complex systems.

Because of the nature of the computer modeling, it is most efficient for two teams to work in parallel. One is a small team of modelers who will develop the mathematical details of the computer model; and the other, larger team will continue to conceptualize the model and question the assumptions of the small team. The small team must include an experienced modeler or have access to one who can periodically review the model.

larger team
- stock and flow

smaller team
- detailed computer modeling

model conceptualization
- model verification
- critical parameter estimation

and simulation
- data collection to support model

The larger team should have enough familiarity with the model to feel ownership and be able to use the model themselves by the end of the process. The small team with the intimate knowledge of the model should be capable of continuing to refine the model and helping others run different scenarios with the model.

8. Analysis and evaluation - approx. 2 weeks
Model testing is a critical phase and in system dynamics, involves more than just collecting historical data for regression analysis. While the degree of testing required depends on the ultimate purpose of the model, Forrester and Senge (1980) outline the basic elements of testing necessary to ensure a robust model. Their tests include structure verification, parameter verification, extreme conditions, boundary adequacy, dimensional consistency, and a series of model behavior tests for sensitivity and replication of historical data.

9. Policy analysis - 1-4 weeks
The final step of the modeling process is to design intervention scenarios that achieve the desired system behavior. Things to consider in policy testing include (Roberts, 1978b):

- accounting for the system's ability to absorb change,
- considering possible impact on other systems,
- and accompanying new policies by management re-education and/or explicit decision rules.

To increase the chance of implementation, the project process should be designed to produce implementable results, a desire to implement, and an environment that enables implementation. Roberts (1978) suggests that the facilitator:

- establish expectation that work continues until implementation is achieved,
- maximizes in-house involvement in the process,
- quickly develop the initial model,

- models in enough detail to be sufficient for persuasiveness,
- gears validity testing to management concerns,
- and designs measures of effectiveness into the model that are consistent with the real world.

The final step of the modeling process depends on the intended role. For example, models designed for management flight simulators require an additional step in which the interface between the model and the users is designed (See section 4.2.4 for details on management flight simulators).

Robinson (1980) warns that it is much too easy to get mesmerized by the model. It is critical, therefore, to keep a clear mental model of the real world throughout the model building process.

4.4.2 Designing a System Dynamics Infrastructure

The goals of a system dynamics infrastructure are to support internal systems modeling efforts by providing:

- modeling and facilitation expertise,
- an awareness to the wider organization of SD as a methodology ,
- systems thinking workshops,
- and access to previous models and insights (organization memory).

The term "expertise" in this context is the ability to facilitate group conceptual modeling sessions and to lead a project in designing a system dynamics computer model. Interviewees who have been through the experience of building models stated that modeling is difficult and time consuming, which will ultimately result in few people within an organization developing this expertise. For example, one person estimated in his vision of an infrastructure that there would be about 5 or 6 dedicated modelers for a company of 15,000 people.

The computer software for system dynamics has become increasingly user-friendly over the last decade, freeing the modeler from struggling with the technology (Gould, 1993). But three of the practitioners interviewed warned that while people can be capable of building models within a week's exposure, gaining the experience necessary to build good models can take anywhere from 2 -10 years (depending on the criteria for judging the model to be "good"). Almost all the people interviewed thought that even though only a few people are likely to become experts in the computer modeling, the conceptual modeling skills and an awareness of why computer simulation is useful would be appropriate for everyone. Accepting this as a premise, the question becomes where and how the expertise should be located within the organization.

Ideally, the managers trying to make decisions in dynamically complex arenas should be able to model for themselves. But as discussed in the section on modeling for corporate design, this would require a redefinition of management. Managers currently have time demands and a decision orientation that makes it unlikely that they will model for themselves. Therefore, support modelers are necessary. While consultants can provide expertise and often have credibility to cut through the politics, they are only around as long as the duration of the funded project.

A dedicated inside group would have the advantage of having the time and task to become proficient in the modeling and would also have an incentive to see that system dynamics is used in the company. However, resources dedicated to a "process" activity are usually the first to go under a budget crunch. This would make the entire effort rather vulnerable. Senge (1993) states that managers are the only effective people in making learning happen. He sees the role for support people to be the design and facilitation of learning experiences (but always in partnership with line management) and to guild the diffusion of learning, which would include managing the library of models and the growing organizational memory. Having a dedicated group should provide modeling support for those that do not have the time, inclination, or experience to model for themselves, but it should not preclude anyone from learning to do so.

If the purpose of having an official infrastructure is so that people can tap it for training, facilitation, and organizational memory, it needs to have both credibility within the organization and a mission aligned with these tasks. The group's mission should be to:

- identify and execute real applications,
- develop a process for organizational entry of system dynamics,
- develop a formalized process for SD methodology,
- and continue to maintain models that have more potential applications.

A more realistic alternative to having a dedicated system dynamics group would be to integrate the system dynamics support role into a pre-existing group with a compatible mission. It will likely be necessary to spend some time interviewing in an organization to find an appropriate match with an existing credible group. The "home" for system dynamics should be consistent with the intended business role and modeling purpose. One successful example is Royal Dutch Shell's Group Planning described in Section 4.2.3. The business role of this group was to provide strategic planning support to the business units. They evolved a "home" for system dynamics over time that fitting both their business role needs and their modeling approach of provided scenario based strategic planning. Some other possible homes that the interviewees suggested are:

Training and development

Training groups, sometimes imbedded in a human resources department, are already tasked with assessing and sharing new process tools. In this way it is an ideal place from which to spread awareness and hold the systems thinking workshops. This might also be a good group, depending on the reputation within the organization, from which to create managerial practice fields. The common problem with training and development groups is that they are not engaged directly in helping solve business issues, nor do they tend to be technical modelers.

Internal consultants

Some bigger organizations have groups of internal consultants that can provide a home for system dynamics expertise. Often these consultants act as internal process facilitators on demand for the rest of the organization. This is a great match for the systems thinking facilitation role, but does not necessarily lead to getting people interested in modeling. There might not be the structure for providing the organizational "memory" role either. System dynamics could be another tool for these people. However, the definition of these groups is usually flexible enough to fit the needs of a system dynamics infrastructure.

TQM infrastructure

There is natural fit between system dynamics and Total Quality Management (TQM). Generally speaking, TQM is a both an customer oriented quality philosophy and a specific set of tools that has been credited with leading to substantial improvement for many businesses in Japan and America (Kim, 1990). The system dynamics approach would allow a TQM analysis to move from static to dynamic modeling. Kim (1990) also suggests that there is a basic philosophical compatibility between TQM and systems thinking. The emphasis in TQM is generally on operational learning (know-how) while system dynamics focuses on conceptual learning (know-why). Where TQ focuses on the analysis of the separate parts, system dynamics strives to capture the patterns of interrelationships making up the "whole". Kim sees the integration of these perspectives as a significant step towards enhanced organizational performance.

The natural use for system dynamics working through TQM would be in the process of continuous self improvement. Another advantage is that the traditional TQM tools are quite supportive of the data collection and problem identification phases of an SD model building project. However, TQM efforts traditionally focus on the internal processes and improvements and there is a chance that system dynamics would not be used in the strategic planning arena of the company.

4.5 COMMON INTRODUCTION STRATEGIES

This section presents the introduction strategies that were described during the interviews with practitioners and company representatives. Three different strategies stood out from the interviews. The first strategy is referred to as a "project based introduction," where internal interest is generated through successful business issue oriented projects. The second strategy is based on a specific series of cases from the Organizational Learning Center, where system dynamics is introduced as part of a broader organizational change effort. The last strategy is called the "mandate strategy." Here system dynamics is essentially introduced through management mandate. Finally, a series of general tips and concerns about introduction strategies and developing internal competency are presented.

4.5.1 Project Based Introduction

The project based introduction was the most commonly discussed strategy for introducing system dynamics into an organization. The basic intention is to develop internal demand for system dynamics facilitation through project based success stories. The interviewees found this kind of "pull" based approach more attractive than management mandates because it allows the managers who are ready and interested to find SD at their own speed, rather than being put on the defensive. The first part of this strategy would be for a "champion" within a company to sponsor a pilot project using system dynamics to explore a business issue. This project gives the involved internal team an opportunity to test out the methodology, and will hopefully leave them knowledgeable about SD and with an initial success story to tell. This success increases the organization's awareness of the champion who is using system dynamics and of the potential of the process.

A rough vision of this introduction strategy is:

- initial test project, leading to a success story
- internal expertise begin in the one or two people in each project that are most interested in the modeling and self-select to work closely with the outside expert
- other managers, facing difficulties themselves, see success story and request similar facilitation support for a project
- most interested people from first project continue to work and take on more of a facilitation role
- as projects continues, core of expertise develops and the consultant involvement phases out from lead modeler to occasional review
- over time, people throughout the organization become familiar with system dynamics and have access to modeling support

One practitioner said that an important consideration in the initial project is to carefully maintain a balance between the depth of the problem being tackled and the risk of failure. A failure can quickly dampen the early enthusiasm, while addressing too trivial a problem shows no advantage to using system dynamics. It is also important to keep the investment in the modeling projects to a minimum in the beginning to allow time to learn how to use the methodology effectively in the company without having high expectations of results.

Case Example

A manager in an engineering group of a large manufacturing company recently became interested in systems thinking while reading Senge's *The Fifth Discipline.* His concern over the lack of a validation methodology at the systems thinking (causal loop diagram) level led him to investigate system dynamics and take a summer course at MIT. To him, the time felt "right" in his company for introducing a new perspective. The market outlook was gloomy, but the company had very bright motivated people looking for a new direction. To introduce system dynamics, he sponsored, both financially and as the "champion", a modeling project examining an internal issue around growth. Initially he ran into problems from trying to "force-fit" the issue into one of the archetypes. But before floundering too much, he brought in an outside consultant to facilitate the modeling process. One of the important characteristics of this project was that even though it addressed a real issue where there was "pain" in the group, the team was able to create a relaxed, experimental environment. He thought it important, particularly in the first project, not to risk the eternal reputation of system dynamics in the organization by addressing too critical an issue.

Hearing about this project inspired one of the manager's coworkers to ask for help in addressing a recurring troublesome problem. This was an area that our manager had considered to be in *real* pain. As the manager's experience in these projects increased, the modeling teams began addressing more and more risky problems. At present, this manager has what he calls a "skunks works" internal consulting group that operates unofficially out of his engineering group. His long term vision for system dynamics is that it should be part of the management engineering services group (outside of the functional areas) that already does internal consulting, statistics, and optimization model decision risk analysis. To date, he has found people in this group to be resistant due to their perception of themselves as "the experts" - if they haven't heard of it, it can't be that valuable.

He is currently continuing to build awareness and endorsement for the methodology through the organization. Energy is still required from the outside (the consultant and the champion) until some anticipated critical mass is reached. He felt that the relative use and internal capability must grow together through this process and thought it was important to write up case histories of each project in order share the stories and learnings. He compared his efforts to the decade long process of introducing quality management into his organization. In both cases, the company had to move from understanding the basic philosophy, to formally using imposed methods, and ultimately to internalizing and fitting the methodology to the needs of the organization.

This manager and the consultant who worked with him saw the success factors in this case to be:

- access to budget
- personal commitment of the champion
- credibility of champion
- time was "right" in the company (need seen, and time was available)
- senior level people were involved in the causal loop diagramming, though not the computer modeling
- R&D attitude of modeling teams
- use of small models with heavy involvement
- use of an outside consultant to introduce new tools

One weakness with this approach is that an ongoing role for system dynamics is rarely planned into the initial project, so that the members of the ultimate envisioned "home" group are not owners of the initial process. As the manager in the manufacturing company discovered, it is not easy to get a group to take ownership of a process after it is perceived to be someone else's baby.

4.5.2 The Organizational Learning Center's Approach

Out of the five disciplines that form the OLC's foundation of organizational learning skills, the "fifth" discipline of systems thinking is considered to provide the central framework. Many of the OLC researchers have a background in system dynamics and believe strongly that systems modeling has an important role to play in a "learning organizational". The OLC currently has on-site long term pilot projects with 5 or 6 companies. The objectives of these pilot projects are, in general, to help the companies become more effective through the practice of the disciplines and to begin creating a learning environment while working with significant business issues. The OLC approach has been to not focus on systems thinking or systems dynamics as a separate tool, but to use them as part of the larger toolbox of learning organization disciplines.

Interviews with two OLC researchers knowledgeable of system dynamics revealed a vision of how system dynamics would be introduced through the pilot projects. The process envisioned is:

- ground managers in the archetypes (generic systems thinking stories[10]),
- expose managers to a generic model structure through a management flight simulator focusing on an issue relevant to the pilot project, such as product development, service quality, supply chain, etc.,
- build modeling skills and confidence in a few interested people within the company, by learning about the generic model behind the flight simulator,
- increase modeling competence by having the interested people (under guidance from the OLC researcher) adapt the flight simulator to look more closely at specific issues in their organization,
- and finally, encourage the internal interested people to model other issues, slowly phasing out the help of the OLC researcher.

Our experience over the last couple of years has been that the use of the management flight simulator has not led directly to conceptual or computer modeling. The management flight simulators are typically introduced during

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10 See Senge's *The Fifth Discipline* for a discussion of the different archetypes.

a learning lab where mental model communication skills, visioning, and systems thinking are also introduced (Kim and Seville, 1993). In the past, participants of these introductory workshops reported learning from the systems thinking and the simulator, but were more inspired by the communication tools. In response, the pilot project's ongoing work focused on the disciplines of mental models and vision, and in the case of one project, have actually moved further and further away from using even causal loop diagrams (Seville, 1994).

From discussions with people on both sides (MIT and company) of the pilot project, it seems that the communication tools are more attractive because they are easier to work with and produce immediate results. They help the organization deal much more productively with issues that, working together, they can handle at the "traditional" level of thinking. But rather than replacing the need for systems modeling, the communication skills should also enable the managers to recognize the dynamically complex problems that can't be dealt with at this traditional level of thinking. This should lay a foundation for a learning environment ideal for the experiment learning atmosphere characteristic of the modeling for learning approach.

Open questions that remain include:

- Will the pilot projects naturally progress to conceptual and computer modeling without special intervention? How long will it take?
- Should the modeling have been introduced as an integral part of the disciplines rather than a distant extension of the flight simulators?
- Should a role for a few future internal modeling experts have been designed into the pilot project from the start?

There would seem to be a great potential for introducing system dynamics through these projects because each pilot project is a long term cultural change effort that ultimately requires the development of an internal learning infrastructure - one that could provide a place for the system dynamics support structure.

4.5.3 Mandate Strategy

One tempting approach is to simply train internal people in system dynamics through some of the short courses offered and allow them to self select usage in the organization. The general feeling among the interviewees was that deliberate institutionalization through mandated "training" does not work well as an introduction strategy because new tools should be connected to something the organization cares about (Beer, 1992; Graham, 1993). This was often found during the TQM experiences in many companies: management-dictated tools, particularly when management itself does not use them, are resisted.

Another concern with this approach is that while the basics of system dynamics modeling can be learned fairly rapidly, it is more difficult to learn how to identify problems that are appropriate. Rather than just training people and expected them to choose when and where to use system dynamics modeling, one of the practitioners thought that the most appropriate role for "training" is to prepare teams about to embark on a facilitator guided modeling project.

4.5.4 General Introduction Strategy Tips

These general tips are factors that practitioners have found to significantly contribute to the success of both individual modeling efforts and longer term system dynamics introduction projects.

Project Sponsorship

A reoccurring success factor has been the presence of a committed, internally credible champion. The ideal personal commitment would include a desire to personally participate in the project. Change projects such as introducing system dynamics can be further facilitated by having a steering team to share ownership in the process. The champion or steering team needs to work with an outside expert to plan the change effort, including:

- strategic specification (select what to change)
- design (how to change)
- pilot (first test case)
- production (roll out)

Based on his experience as a consultant participating on change projects, Graham (1993) outlined a range of variables that need to be managed by the core team-

- executive support - including resources, input on "issue", rare interventions, input on "solution", and visible leadership
- common language - avoiding creating a project language no one else can understand
- program management support - at least one dedicated person; everyone else in the project will most likely be doing this in support of their full time job
- the wider goals and support for organizational change
- continuous diagnosis of the change process

Consultant support

Introducing system dynamics does require an outside expert modeler. Rather than attempting an independent project as soon as the in-house modelers gain experience, slow phasing out of the outside expert has been found to be a much more effective approach by some of the company representatives. Steps might be:

- consultant is the facilitator and lead modeler, working closely with 1 or 2 people who would like to learn modeling
- consultant leads the problem definition and conceptualization phase, then acts as a mentor to the internal modelers
- consultant is the quiet partner while internal modelers lead the project
- consultant is not present during the model building meetings, but occasionally reviews the model
- finally in-house modelers act independently, unless crisis is reached

Motivation

The time when people in an organization perceive the need for change is a time when they are most likely to be willing to experiment with new ways of doing things, such as system dynamics. The dilemma around timing change efforts is that when the need to try something new is high, it is usually during a time of crisis when there is no time or money to invest in learning. On the other hand, when times are good and there is both time and money to invest, organizations rarely see the need to change their ways of doing things.

In an effort to understand why the use of system dynamics had faded after an introduction effort, an inside person who had developed skill at modeling was asked when she might use system dynamics in day to day work. Her reply was that she would use it only if she perceived that management thought that it was very important and that someone wanted or was interested in the results. Otherwise it was not worth the time investment away from tasks that there was pressure to complete.

Team's environment

Like many decision support processes, system dynamics can be most effective in a team that has a level of trust and openness that enables people to share the way decisions are really made in the organization. Creating a trusting environment is a complicated phenomenon, but can be facilitated by grounding the team in mental model skills. The mental model skills help people recognize the strongly held assumptions and provide a guide for exposing each other's assumptions in a less threatening manner. Since the process of developing causal loop diagrams is essentially revealing mental models in the team, the more effective people are in understanding why they have the causal theories they do, the more effective the team will be in developing a shared understanding.

Diffusion

Assuming that one of the goals of the project is to test system dynamics and eventually share it with other projects, diffusion should be designed in from the start. The initial project needs to be credible, both from having a credible champion and from working on a concrete problem. Insight from the modeling process needs to be made accessible to the wider audience.

4.5.5 Developing SD competency

Internal expertise needs to be developed both to continue working with models after the construction phase has ended and to build up the capacity in line with the organization's vision of its system dynamics infrastructure. (The requirements of the internal experts were discussed in the section on system dynamics infrastructure.)

One of the difficulties in developing expertise is that while people can learn the tenets of system dynamics and the mechanisms of the software rapidly, the most experienced modelers interviewed believe that it takes many years of practice to develop the experienced judgment and intuition that is key to good modeling (Forrester, 1971; Senge and Sterman, 1991). Presently, system dynamics modeling is still very much an art rather than a science.

With this in mind, visions of training people in a company to be familiar with the software and then expecting instant competence at modeling is unrealistic. Worse, poor modelers will develop low quality models which could lead to a poor reputation for system dynamics as a policy tool - ruining any chance for the methodology in the company.

Richmond (1993) suggests that systems thinking and both conceptual and computer modeling involve thinking at a very different level from the traditional event-oriented level. Richmond goes on to say that systems thinking really requires operating with seven different kinds of thinking skills:

- dynamic thinking (behavior over time instead of events),
- closed loop thinking (feedback),
- generic thinking (recognizing fundamental similarities),
- structural thinking (seeing the structure that drive behavior),
- operational thinking (difference between math and reality),
- continuum thinking (continuous simulation, etc.),
- and scientific thinking.

He concludes that explicitly addressing these tracks during the learning process is more effective than trying to teach everything at once under the general umbrella of system dynamics.

The average estimate from the practitioner interviews was that it takes from 2 to 4 years of working on projects to become skilled at modeling. An example of a learning progression is:

- begin with causal loop diagrams and stock and flow perspective,
- learn mechanisms of a system dynamics software package, through a project or through a short course,

- work with the classic (generic) models as starting point,
- balance working with experienced practitioners with personal experimentation,
- formalize study plans so others can follow,
- and begin teaching systems thinking and facilitating model building projects, leverage outside consultants early in the process.

4.6 COMMON BARRIERS TO SUCCESSFUL SD INTRODUCTION

Along with trying to learn from what has worked in the past, we must learn from what has prevented success in the experience of both organizations and consultants. The problems encountered fall into two categories. The first are factors that can inhibit a single project from succeeding, and the second are the variables that can prevent a successful project from having any lasting impact on the use of system dynamics in the organization. The following is not a comprehensive lists of problems that have to be overcome, but it does show the major barriers that consultants, academics, and people in organizations have discovered in their experience. The list was created by taking individual points raised during the interviews and grouping them into common themes.

4.6.1 Barriers to a Single Successful Project

The *time* required to build a good model is intimidating because:

- time spent not visibly working on the "product" is often perceived as a waste of time,
- the long term time frame of modeling is a very different way of thinking,
- and modeling process concerns are not given the same legitimacy as product concerns in many companies.

The *project team* can be a barrier to success if they have:

- no power in the project team to take action in the way that the modeling effort suggests (feeling of helplessness),
- insufficient knowledge to address the issue,
- no credibility within organization to move insights into action,

- a tendency in the team to point to outside factors - perhaps indicating no willingness to personally change,
- unwillingness or inability to tell "the truth" (face saving, etc.),
- or pre-model solutions or premature consensus by the team.

Having internal *ownership of modeling process* is important because:

- implementation requires the "buy-in" of the decision makers,
- and consultants ("the outside experts") are in and out of the company based on budget. The manager has to move from faith in the consultant to a deep understanding of the model because acting on the results usually includes taking personal risk and being challenged.

The *modeling process* itself can be a barrier if:

- models are expected to be crystal ball predictors, not a learning tool,
- models are seen as only good as long as the relationships are constant,
- at the end of the process, it is hard to tell if the model is really more accurate than a guess, but it clearly takes much more time and effort,
- there is no data to build "traditional" confidence into the model (statistical validation),
- people already have an answer and just want to use the tool to verify something they believe in,
- the modeling is without real need, leading frequently to low energy and credibility,
- or people are willing to go along with a process, but are not willing to go along with results that they don't like.

These aspects of *"traditional thinking"* can be barriers:

- event orientation: can't get past the details to look at the patterns over time,
- data driven mentality: difficult to think conceptually or generically,
- belief that we are unconnected individuals in the system,
- static thinking: difficulty in leaping from Paredo charts to systems modeling,
- concept of modeling social systems -people are not used to it and can be resistant to the idea that their decision process can be modeled,

- most business people do not have much experience in modeling - many good models are developed and them left on the table simply because no one related to it,
- and the gap between designing the system and operating it: managers are currently focused on operating the system.

4.6.2 Barriers to Diffusion

Lack of a *business role* inhibits further use of system dynamics because:

- after a single project, people with new modeling skills often do not know where to use the modeling in the company, nor is there demand for it,
- management accountability often does not connect long term consequences with the actions that led to them, so managers have no incentive for long term planning,
- and the new structures suggested by a modeling project can threaten traditional norms, habits, and assumptions (Senge and Sterman, 1991)

The *expertise* necessary for a modeling project is a barrier to continuing projects because:

- lack of skill within the company means they are dependent on consultants,
- companies often can't dedicate a person to SD modeling because resources are scarce,
- modeling is difficult (requires hard thinking),
- 10-20% of people are not exciting by the conceptual modeling and over 50% do not resonate with computer modeling,
- 90% of all the model designed now are poor quality models,
- and the system dynamics approach is easy to understand but difficult to apply.

Motivation issues that deter the use of modeling include:

- no corporate "pain" often leads to people being comfortable with the way things are done and not seeing reason to use new approaches,
- lack of management demand for process improvements,

- and if SD is perceived as another "fine" program - why is this approach that management is telling us to use any different from the last 20 that were pushed on us?

Lack of *credibility* can come from at least two sources:

- if the sponsor of the system dynamics introduction is not a respected, credible source in the company people, diffusion attempts will often be met with resistance,
- and if the modeling project was not seen as being the right team looking at an appropriate problem, the "success story" lacks credibility.

CHAPTER 5

EMERGING FRAMEWORK FOR INTEGRATION

The emerging framework for integration outlines a process for designing an integration strategy to fit the conditions and goals of a particular organization. There are two major sections of this chapter, a theoretical framework for how to design a strategy, and a case study example, which is the strategy that was designed for Bose.

An "integration strategy" is a long term strategy for how an organization will implement its vision of internalizing system dynamics in support of ongoing policy making and decision making. The previous chapter explored the different ways in which system dynamics can assist policy making, along with some guidelines for application. This chapter takes the next step and explores the central questions concerning integration, including:

- what kinds of policy making will system dynamics assist?
- how can system dynamics be used to support this kind of policy making?
- who will use it?
- who will provide the expertise and how?
- how can system dynamics be made accessible and how should it be introduced?

5.1 DESIGNING AN INTEGRATION STRATEGY

A typical scenario where a system dynamics project might be initiated is when a person in an organization learns of system dynamics and is inspired to sponsor an initial project to "see" how SD works in practice. This "champion" may seek out a consultant to provide the expertise. While many SD projects are initiated with no further explicit goal than exploring a specific issue, some projects are also run to "field test" with the hope that if the initial project is successful, system dynamics will spread and play an ongoing role in the organization. My overall impression from the data collected and analyzed is that many of the projects intended as a starting point for an ongoing use of system dynamics fade away, even after a couple of successful projects.

This framework is not a definitive answer to how system dynamic should be introduced so that it will be permanently adopted, but rather a guide for developing a strategy that should increase the chance of system dynamics being internalized into the organization. In essence, the goal of the strategy is to make explicit a long term vision for where and why system dynamics will be used, and how the expertise will be provided. This vision should guide the process of introducing and experimenting with system dynamics. I believe this will increase the chance of system dynamics being used after the preliminary push, because managers will know what problems to apply system dynamics to, who in upper management is supporting his/her use of time, and how to work with the expertise that is developing internally.

The four aspects of the integration strategy design framework are:

(1) defining a business role for system dynamics,
(2) selecting a compatible modeling purpose,
(3) developing an internal support infrastructure,
(4) and designing an introduction plan.

It is, however, expected and desirable for an organization's vision of how system dynamics should be used to evolve with experience. The integration strategy should ultimately be developed with an internal steering team whose mission is to work with a practitioner (SD expert) to oversee the introduction efforts. The role of the steering team and some general introduction concerns were discussed in Section 4.5.4.

5.1.1 Defining a Business Role

Much of the interviewing effort focused on surfacing ideas about appropriate "roles" for system dynamics. This was motivated by data that emerged early in the research, which suggested that the lack of a shared vision around the intended future for system dynamics was a key factor in the short active life of SD that followed some of the introduction efforts. The early data came from interviews with people in companies who had developed a working knowledge of the methodology by participated in internal system dynamics projects. During the interviews, they were asked if they continued to apply system dynamics, and if not, why not. Comments included:

> "I thought it was a useful approach, and I continued to build personal model for some time. I stopped after a while, because there was no "pull" from the rest of the company."

> "I would model again, but only if I was asked to by upper management or knew that someone cared about the results."

> "I found it difficult to know when to use the modeling. It takes too much time away from more directly pressured tasks to use very often."

> "We made a series of good models, but don't know what to do with them now."

Discussing this data with some of the practitioners who were interviewed led to the suggestion that perhaps a clear vision of a business role for system dynamics would have helped these people know when and why to model. A "business role" is a role that SD is envisioned to play in the process of designing policies in the organization. A role should be defined with an understanding of the ways in which system dynamics can and should be used (discussed in Chapter 4) and matched with an appropriate need in the organization. Multiple roles are certainly possible and encouraged, but it is preferable to begin with a shared picture of a focused role during the introduction and experimentation efforts.

The first step in the integration strategy design is to, while keeping an awareness of the guidelines for applying system dynamics in policy making, identify the most appropriate initial business role. To do this, processes by which different kinds policies are made in the organization, and any particular "needs" that system dynamics could support, should be understood. "Needs" and policy making processes can be surfaced from the mental models of the steering team and through interviews with people across the organization, focusing on what they think the critical dynamic issues facing the company are.

The data collection process that was found to be effective while defining the business role for the case study strategy has two parts.

1) Interviews with people in the organization that have had previous exposure to system dynamics. Questions included:
   - what was your past experience?
   - how do you think SD could best serve the organization?
   - what were the previous problems encountered?

2) Interviews with policy makers, from mid manager through to senior management. A 10 minute overview of system dynamics was given to those interviewees unfamiliar with the methodology, before any specific SD use questions were asked. Questions included:
   - in your experience, what are the current policy making processes?
   - do you see any areas where "help" is needed?
   - where do you think a tool like system dynamics could help?
   - do you think people are open to that kind of process?
   - based on the business needs, how would you envision system dynamics being used?
   - who would use it?

To surface some examples of possible business roles, the company representatives and practitioners who were interviewed were also asking to share their personal visions of an ideal role for system dynamics. The practitioners tended to express visions in terms of the modeling purposes described in Section 4.2. The company representatives shared images of specific business support roles. Some of the business roles that were suggested are:

- executive strategic planning support - this would require detailed, well tested models and possibly scenario workshops, since the executives will probably be too busy to develop the model themselves
- a separate group in charge of model building and policy testing to report to the senior managers

- a powerful tool in the TQM toolbox, both the model building process and the ability to keep working on models to share with other teams
- provide a practice field for decision making for managers - they need a risk free environments to talk about the "sacred cows" of the organization
- model and redesign the major process structures such as the product development process and the manufacturing processes
- use models to monitor and measure internal systems - could be used to identify and set realistic goals
- support mid-level planners for systems such as inventory control
- require a "loop analysis" with major reports involving dynamic issues
- institutionalize continuous improvement process through modeling for learning - each team dealing with ongoing policy concerns could meet a day every other week to continue exploring issues

5.1.2 Selecting a Modeling Purpose

The modeling purposes described in Section 4.2 have different requirements, processes, and end-products. Each can support a chosen business role differently, and there are compatible matches that can be found between the goals of a business role and the characteristics of a modeling purpose. There are two levels at which the compatibility should be considered; the overall characteristics of the business role, and the goal and issue being explored in each individual modeling project.

Figure 18, presented in Section 4.2.7, is a summary of the defining characteristics of each modeling purpose. To find some overall compatibility trends, these characteristics were matched with the needs of some of the business roles discussed in the previous section, as displayed in Figure 20. The appropriateness of each match is judged on a relative high/low scale. The modeling purposes are presented in the order of the *expertise and organizational infrastructure necessary.*

Strategic planning can best be supported by modeling for policy design and modeling for scenarios. This is based on the descriptions during interviews where strategic planning was said to require robust models with high emphasis on realism. What this grid shows is that the modeling purposes can be used to sequentially support strategic planning, starting with developing a model for policy design and testing, then using the model for scenario based workshops with a wider audience, and perhaps eventually incorporating the process into upper management.

Business Role

Modeling for:	strategic planning	major process design	TQM support	monitoring internal systems
learning	Lo	Lo	Hi	Lo
practice field	Lo	Lo	Hi	Lo
policy design	Hi	Hi	Lo	Hi
scenarios	Hi	Lo	Lo	Lo
organizational memory	Hi	Hi	Hi	Hi
corporate design	Hi	Hi	Lo	Hi

Figure 20. Compatibility between Modeling Purposes and Business Roles.

Using system dynamics to support major process design was described as having mid to upper-level management (level below executive) use SD models to "re-engineer" major processes such as product development and manufacturing. The interviewees who suggested this purpose described a need for detailed models that can be used to compare the performance of the old system with the performance of design alternatives. This business role is best achieved through policy design and testing, and supported by organizational memory.

The TQM projects mentioned during the case study interviews were usually described as being numerous, insight and education oriented, and relatively low investment; a good match with the characteristics of the modeling for learning approach. Practice fields are also an excellent tool for supporting

TQM efforts, because they can be used to create an environment where teams across the company dealing with similar issues can "practice" making decisions together.

The final business role presented is monitoring internal systems. The goal of this business role is to develop computer models of the current systems that have measures similar to the real world. These models can then be used to assess and optimize the performance of the real system relative to what the model suggests can be achieved. A model serving this function would need be detailed and very well tested against the historical performance of the system. Modeling for scenario workshops is relatively less compatible because the emphasis in this business role is on having a small team of modeling experts continually work with the model, rather acting as facilitators during workshops with managers.

Figure 20 is intended to be a rough compatibility guide. The modeling purpose pursued in each individual modeling project should be, of course, chosen on the basis of the goals of that particular project. Again recalling Section 4.2.7, Figure 19 shows some major characteristics of models commonly developed under each of the modeling purposes.

The reason for identifying the overall compatibility match with the business role is to more accurately define the requirements of the modeling infrastructure that is intended to support the chosen business role.

5.1.3 Developing the Infrastructure

Having developed an initial vision of the business role and the general modeling purposes that are going to be adopted, it is time to think about how such activities could be supported within the organization. Two choices for developing a system dynamics infrastructure are either to develop a new group or to integrate it into an existing organizational structure. As mentioned, possible "homes" that already exist in organizations include:

- training and development groups,
- TQM infrastructures,
- strategic planning groups,
- and internal consulting groups.

A good process for identifying such a group would be to work through the steering team and interviews to examine existing groups and locate people who might be well suited to support this kind of modeling activity. The criteria of such a group was discussed in the Chapter 4 section on designing system dynamics infrastructures, Section 4.4.2.

An appropriate approach would be to interview other internal process support personnel. The goal is to locate a possible alignment between the current responsibilities of a group and the requirements of supporting the business role. Questions should include:

- what is your function, how do you support decision making?
- based on a description of SD, would those skills fit into your group?
- could your group support the intended business role?
- what are the limitations from associating system dynamics with this group?
- how would the group have to evolve in order to carry out the role of supporting SD projects in the company?
- who else should I speak with?

Additionally, the likely "consumers" of system dynamics modeling projects should be interviewed to ensure that any modeling support is done through a system that they perceive as credible.

5.1.4 Designing an Introduction Plan

The introduction plan should introduce system dynamics in a pilot project experimental mode that is aligned with the vision of the business role. A sequence of projects should be planned to build expertise (infrastructure) that can support the compatible modeling purposes. Questions that need to be asked include:

- what is the process by which new missions and tools are added to the targeted infrastructure?
- what would be required to get "buy in" from the people who select the new tools?
- who are the potential people who could become the internal experts?
- who would be a credible champion to sponsor system dynamics?

- how would we set up a test project?
- what is an appropriate first issue?

General elements of the strategy
I suggest following the project based introduction strategy (Section 4.5.1). The projects should focus on exploring business issues consistent with the long term role envisioned for system dynamics. People from the proposed "infrastructure" should participate in the initial project so that they will feel ownership in the process. They can then see how the methodology could fit into the structure of their group.

The basic steps are:

- get together a steering committee to develop the integration strategy "vision" and sponsor the project
- run a pilot project, including:
  - issue selection, in line with business role
  - modeling purpose selection
  - problem selection
  - proceed with modeling process, minding the common barriers
  - document experience
  - publicize success without pushing
- continue building expertise through additional projects that are increasingly led by internal people and initiated through the proposed infrastructure
- phase out the consultant
- supply energy from steering committee until there is a stable demand for projects and supply of expertise

5.2 CASE STUDY PART 2: INTEGRATING SD INTO BOSE

The following strategy is my response to the question about system dynamics posed by Bose in the beginning of this research, "what do we do next to bring it into the organization?" The strategy is based on specific interviews within Bose that were guided by the framework for integration presented in the previous section. The strategy will be presented through the four components laid out in the first section of this chapter. The summary of the integration strategy is as follows.

- The initial business role will be to understand and improve internal processes (as opposed to products) in support of the ongoing total quality efforts.
- The primary modeling purposes will be to explore these processes through the modeling for learning approach and to maintain models for organization memory.
- The support infrastructure for the system dynamics efforts will be imbedded in the existing total quality structure.
- The introduction plan will follow the project based diffusion philosophy and will involve a credible sponsor and the primary organizers of the current quality improvement efforts.

5.2.1 Strategy Design Process

The first step in the strategy design was to collect data through interviews with Bose employees. The interview choices were initially guided by the research steering team (myself and the three Bose managers), and then became an evolving process where one interviewee suggested the next. A ten minute overview of system dynamics was given to those interviewees unfamiliar with the methodology before any questions specifically relating to SD were asked. There were four stages of interview, with:

1) people with previous system dynamics experience to surface their impressions about an appropriate role for SD
2) policy makers to learn about current "needs" in the company
3) internal process consultants to find a compatible existing infrastructure
4) people in the potential infrastructure and proposed business role to surface the requirements of an introduction strategy

The interview questions followed the format laid out in section 5.1. A total of 14 people were interviewed in the course of the data collection. I conducted all of the interviews, and the research steering team helped interpret the data based on their understanding of Bose.

5.2.2 Emerging Business Role

The initial business role for system dynamics in Bose emerged from interviewee's thoughts on the existing "needs" in the policy making process and their personal opinions of how SD should support the business. The strongest needs that emerged from the interview process concerned the understanding and management of internal processes. Comments included:

> "A process that should be modeled is research and development to explore how products can get to market faster. This is a re-occurring issue with a long time frame, ideal for modeling. An interdisciplinary team to address the question of time to market would be very appropriate."

> "Modeling is needed because there are things outside our intuitive scope - fairly simple minded things such as inventory control. Currently, we make a plan and start to follow it. One day someone looks at inventory and reacts to an oversupply by reducing production. But nobody understands whether there should or shouldn't be inventory, because at this time, the models used are very simple static models. A dynamic model should be used to understand this kind of control system."

> "Could SD help link together all the unconnected tracking measures? All the process measures that we have been required to track are fragmented and it seems that they must be interrelated somehow."

My perception of the need to better understand systems such as the inventory control was reinforced by the interviews with different people around the issue. Each person expressed very different opinions about even the existence of a "problem". There was a clear need to at least build a shared understanding of what was actually occurring.

One senior executive suggested that there were two classes of decisions being made at Bose, incremental decisions and breakthrough decisions. Incremental decisions are the decisions to do more or less of things that have been done in the past. Breakthrough decisions are in areas where the company has no previous experience. He thought that system dynamics could be most effective in examining incremental decisions because there would be a better understanding of the system. He also thought that the modeling would most useful to the upper mid-level managers who focus on the mid-level problems, because they are really the day to day users of the explicit processes. The mid-level managers referred to are the mangers just below the executive level.

Business Role selected:
Based on this data, the research steering team decided that the initial business role for system dynamics should be to support understanding and improvement efforts around internal processes, and not around product concerns. Current process improvement efforts are channeled through the Total Quality (TQ) organizational structure. System dynamics could complement TQ efforts by providing a feedback perspective and a vehicle for exploring dynamic problems.

The team felt strongly that there was an eventual role for system dynamics to play in supporting the "high level" strategic planning, but that initially focusing on the internal processes was a lower risk way of introducing and testing system dynamics while still addressing important issues.

5.2.3 Initial Modeling Purpose
In section 5.1.2., I proposed that the selection of a modeling purpose be based on both the overall characteristics of the business role and the requirements of individual modeling projects. The overall business role is to support internal process concerns through the Total Quality structure. As shown in matrix comparing characteristics of modeling purposes with needs of the business roles, modeling for learning and modeling for practice fields are both most compatible with the needs of "generic" TQ projects.

The research steering team discussed the requirements of the first series of system dynamics projects and decided that they should be:

- be experimental in attitude
- address important business issues
- have low time and financial investment (minimize risk)
- explore issues that have a good chance of generating insight

Again, the modeling for learning approach is most suited for low investment projects where teams are just becoming familiar with the methodology. The steering team also decided that only after the internal modelers gain experience in modeling, and the company learns how to incorporate the model generated insights into policy making, should the modeling projects begin to explore questions that require larger time investments and more "realistic"' models. Modeling for Policy Design and Testing should play an increasing role in these projects.

The second important modeling purpose that will be pursued from the beginning is that of Organizational Memory. The group that is serving as the support infrastructure will also have the mission of maintaining models and guiding teams to relevant existing work.

5.2.4 Proposed Infrastructure

Since the emerging business role for system dynamics is to support mid-level processes improvement efforts, the natural place to look for a compatible infrastructure was in the ongoing total quality efforts. Five interviews were conducted with people associated with total quality (TQ) in Bose. The objective of the interviews was to gather data about the current TQ structure, opinions about how system dynamics might fit in, and what the process would be to integrate system dynamics.

Bose's current Total Quality Structure

In the interests of confidentiality, I will detail only enough of Bose's TQ structure to show how system dynamics modeling can be supported through this structure and why there is a natural compatibility. The mission of the TQ structure is to diffuse quality improvement tools and to support and coordinate quality improvement efforts. These improvement efforts are focused on process rather than product concerns.

The total quality tools are overseen by a TQ "toolbox" manager. His mission is to coordinate the different conceptual aspects of Bose's quality efforts and to look for new supporting tools and theory. At present, there are seven conceptual modules in the TQ toolbox. Each module has its own champion, who is a manager with the ability to facilitate sessions and train other people in a technique. The role of these champions is to provide a coach who can assist people in becoming self-reliant in the application of the quality tools and to demonstrate upper management endorsement. The philosophy of the toolbox manager was that everybody should be able to use these process tools for themselves. He had organized the modules so that each one can be presented to the quality improvement projects when that particular tool is appropriate rather than having extensive upfront training. This keeps the tools imbedded in the business issues.

The primary vehicle for quality improvement projects in Bose are the Bose ® Improvement Teams. The official definition from an internal memo is (BIT Steering Committee, 1993):

> A Bose Improvement Team (BIT) is a group of people who are working together to define or improve a work process. BIT members employ total quality tools to implement their ideas for making the company successful in its goal of delighting customers. The overall goal of every Bose Improvement Team is to help continuously improve the way they do their jobs.
>
> A BIT may be designated by management or may be a volunteer group that forms itself. It usually consists of three to seven members, from one or more departments, one of whom is chosen to act as team leader. When the BIT has completed its improvement work, a standardized work process is in place, ready for further iterations of systematic improvement.

A BIT begins with the discovery of a "weakness". The handbook on BITs teams tells of five ways that weaknesses (thus projects) can be identified (Smith and Roberts, 1993):

- top down planning - a "performance gap" is seen between the actual and the desired level of performance
- voice of the customer, both internal and external customers
- continuous improvement
- KJ analysis
- employee suggestion

There is both an administrator who coordinates and tracks the BITs and a BITs steering committee that oversees the program. When a project is identified, the official protocol is for the team to contact the administrator and fill out a BIT registration form, which is effectively a request for management support. The steering committee then assigns an appropriate sponsor and advisor to support the team. Sponsors are managers who are interested in supporting the use of TQ tools to improve the business or solve specific problems. They provide regular monitoring and "road block removal". The advisor is someone knowledgeable about TQ tools who acts as a facilitator, coach, and teacher for the team.

The BITs handbook goes on to describe management's expectations of the teams. The teams should:

- conduct regularly scheduled meetings,
- identify weaknesses of Bose processes,
- use total quality tools and methods such as the seven steps,
- communicate the team's progress,
- "lock-in" improvements by revising company standards [policies],
- and present improvement information to management and other groups.

Teams are introduced to tools on a just-in-time theory of training. The introductory course that every team goes through shares the TQ philosophy and an overview of the different tools that the team might find useful during the course of their project. Further courses are taken when the advisor sees a match between a tool and a need. In the past year, these project have lasted an average of 4-6 weeks. One interviewee thought that realistically, these projects don't sustain enthusiasm and momentum past six months.

Requirements for supporting system dynamics

While the problem definition and model conceptualization phases of an SD project are similar to some of the TQ tool based analysis, computer modeling is well beyond the scope of the current tool set and support structure. For the TQ structure to support system dynamics both broadly and through BITs, there eventually need to be:

- support and understanding from the TQ "toolbox" manager of how SD complements and is complemented by the other tools - his official acceptance of the tool as part of the wider TQ effort is critical,
- support from the BITs Steering Committee - this is the group that can authorize people to spend time supporting quality improvement efforts,
- awareness among project sponsors so they can better judge the possibilities of what a BIT can accomplish,
- the ability to recognize dynamic problems and a grounding in systems thinking among the advisors who are coaching the teams, so they can appropriately match the need of the team with system dynamics,
- the capacity to give introductory workshops in the conceptualization tools such as mental models, levels of explanation, and causal loop diagramming,
- at least two people capable of supporting system dynamics computer modeling efforts who have the mission to spend time working on these projects,
- and a person committed to maintaining the library of models, who can also stay current in the field's wider development of new techniques and models.

There does need to be a careful distinction between systems thinking (including the conceptual modeling tools) and the computer modeling. Systems thinking should be presented as being accessible and useful to everyone while the computer modeling should only be used by those with the skill or desire to see it happen.

What the TQ Structure offers System Dynamics

Working through the TQ infrastructure will enable the system dynamics projects to focus on understanding and improving internal process issues, the initial business role envisioned. Aligning with total quality efforts provides a complementary process focused environment, an established "umbrella" to work through, a set of tools that can support the model building process, and a recognized home for the system dynamics expertise. The currently used TQ tools include the KJ method, Process Discovery, Paredo diagrams, Scatter diagrams, Cause-and-Effect diagrams, and Control Charts. The BITs are an existing structure that can support systems thinking workshops, the application of system dynamics when it is needed, and a diffusion mechanism through the already formalized sharing of success stories.

Concerns

There are concerns about working through the TQ umbrella that have to be attended to throughout the implementation process. One of the interviewees thought the TQ tools tend to become trivialized in an effort to make them accessible to the masses, which could greatly reduce the appeal and effectiveness of system dynamics. Another concern of working through TQ was that the application of system dynamics might become permanently restricted to the TQ and BIT structures. BITs are the formal application of quality improvement effort and focusing too heavily on supporting them could miss the opportunity to support spontaneous applications during the normal work process.

Concerns about the BITs that were surfaced during the interviews included:

- BITs are relatively new and still on the learning curve
- in the past, the BITs have explored very detailed and concrete process issues at lower levels of management in the organization
- they have not addressed many "significant issues" yet, the issues are self-selected and "easy"
- no one with a vision of the bigger picture is helping guide the questions being asked and addressed

5.2.5 Introduction Plan

The introduction plan has to meet both the requirements of this integration strategy and the general guidelines for successful introductions presented in Chapter 4. Again, this plan is based on case study interviews and conversations with the research steering team. After reviewing this research, the steering team thought that the project based introduction strategy (section 4.5.1) would serve as the most appropriate foundation for this plan.

Overall, the introduction effort should:

- explore process issues,
- use the modeling for learning approach,

- develop a steering committee that includes the TQ manager, a credible sponsor, and someone from the BIT steering committee,
- work through the BIT structure to register the team, sponsor, and advisor,
- select a first problem and project team that is appropriate for SD,
- have a long term plan for building up the infrastructure and the business role,
- and document each project and maintain the models developed.

Project sponsorship

One important success factor is having a credible sponsor for system dynamics in the organization. Eight out of the twelve interviews that addressed this question suggested the vice president of engineering as the most credible possible sponsor. During his interview, he expressed interest in the potential of the methodology, but had reservations based on reading the reports from prior projects at Bose.

The ideal steering team for the overall introduction effort would include the vice president of engineering as potential sponsor, the TQM toolbox manager, one of the current BIT advisors, and the 3 managers who served as the sponsors for this research to take advantage of their experience. Because this integration strategy was not designed with this full team, it should be seen as just a starting point. The steering team would have to participate in the final planning so that the strategy represents the joint agreement and desires of the team. When the integration planning reaches the detail level, the steering team will have to pay attention to avoiding the specific barriers mentioned in Section 4.6.

Actually moving this plan into action would require the support of the vice president of engineering. The research steering team suggested that I, as the outside expert, need to:

- collect data on current re-occurring systemic problems,
- demonstrate to the VP how system dynamics could be useful in these situations,

- and work with the VP, the research steering team, and the BITs administrator to review the details and discuss the fundability of the proposal.

Initial project

The first project of the introduction effort has the dual purpose of addressing a real business issue and of allowing the potential sponsors to experience the process and see for themselves if there is a match with the TQ infrastructure. Two possible approaches to selecting a first project were to work with an existing Bose Improvement Team or to develop a new project around an appropriate problem. Developing a new project made more sense because of the increased flexibility of defining the problem and the project team.

The problem should be important but not urgent. The first project should be seen as a learning experience with no specific business results expected. At the same time, the problem needs to be credible to the rest of the organization so it must be a real problem where there is a significant potential contribution to be made. Suggestions for the first issue area included:

- explore the R&D process to understand and reduce the current time to market
- model the inventory control system
- model a stable process such as the loudspeaker development system
- explore new ways to structure the systems development process

The best first issue area to explore is the systems product development process both because there is a desire to re-design the process and because managers from this area have recently participated in a system dynamics project. The project should be officially registered through the BIT program to begin working through that structure. The project team should consist of the TQ toolbox manager, the BITs coordinator, one of the current BIT advisors who is interested, a cross functional team around the issue, and an outside expert in system dynamics to facilitate the process.

Long term plan to diffuse awareness and build support system

The essential longer term process would be to:

1) give training workshops in systems thinking and develop a course "module" independent of the outside expert
2) have the outside expert act as a facilitator in the short term
3) find an apprentice in the modeling team who can develop modeling expertise
4) phase out the outside consultant in slow steps, from being the primary facilitator to being a mentor for the internal modelers

Eventually, momentum and expertise should develop that will enable the steering team to be phased out and for system dynamics to be more fully integrated into the organizational policy making.

CHAPTER 6

CONCLUSIONS

> *"Such questions are not, of course, precisely answerable. Questions about influence almost never are. But they are askable, and the asking, should we choose to ask, would be a unifying and a shaping force."*
>
> *- Wendall Berry*

System dynamics can provide a vehicle for explicitly exploring questions and understanding how the dynamics of a system will play out over time. The approach can enable policy makers to see the world as an interrelated whole and focus on the tradeoffs between the short term and long term consequences of a policy. Of course, system dynamics is only useful if it is actually applied to policy making situations. The objective of this thesis is to increase the accessibility of system dynamics to organizations by providing a framework for designing an introduction strategy that intentionally incorporates an organization's vision of how SD will ultimately be used to support policy making.

This research was motivated by a personal need to think about how system dynamics could be most effectively introduced into an organization. A company I was working with wanted to know how they could adopt system dynamics into their policy making process. Having no good immediate answer, I initiated discussions with other practitioners, in both consulting and academia, and people from other companies that have participated in relevant projects to learn from their experience. From these conversations, I began to see that not only had the question of how system dynamics should ultimately be used in an organization not been really addressed, but the lack of a clear understanding of where and why system dynamics should be used had undermined the efforts several of the other projects described.

The conclusion that emerged from this research is that having a clear vision of how system dynamics will eventually be integrated into the organization's existing structure can significantly increase the effectiveness of an "introduction" project. The majority of this thesis has focused on how an integration strategy should be designed, based on what was learned from the interviews, SD literature, and personal experience. The first step was to develop some guidelines for applying system dynamics in policy making. The various practitioners' opinions about how system dynamics should be used were synthesized into a set of guidelines that include:

- the different ways in which system dynamics can support general policy making (modeling purposes),
- the kinds of policy issues that system dynamics should address (appropriate questions),
- an outline of a robust modeling process,
- some of the introduction strategies used in the past,
- and the common barriers that have prevented success in the past.

The thesis next presents a framework that emerged from the research for how to design an integration strategy. The elements of the design process are:

- identifying an explicit business "role" for systems dynamics,
- focusing on the modeling purposes that are most compatible with the needs of the business role,
- developing a modeling support infrastructure that can provide the on-going modeling projects with the necessary expertise,
- and finally designing an introduction plan for how this vision will be achieved.

Articulating a clear vision of the long term role for system dynamics should increase the success of internalizing system dynamics because it provides a context for selecting projects and for understanding how the process and results fit into the larger business structure. However, it is also critical to allow the vision to evolve, as the organization gains experience with modeling projects.

Figures 18, 19, and 20 are summary grids about the ways in which system dynamics has and can be used to support organizational policy making. *They* *are intended to be a starting point that provokes thought and discussion among practitioners about how we can begin to provide more robust guidelines for system dynamics projects.* The compatibility between business roles and modeling purposes needs to be investigated more thoroughly, using case histories to support or further refine each proposed connection. The guidelines and emerging framework presented in this thesis will guide my system dynamics practice in the future, and I plan to continue testing and reformulating the theories based on personal experience.

Along with developing a theoretical framework, I worked closely with a case study company to learn from their past experiences with system dynamics and later to design an integration strategy based on the framework. Clearly, the next step for this research is to implement the strategy suggested for Bose and to assess how the strategy design process and guidelines for modeling work in practice.

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APPENDIX A

EXAMPLE OF INTERVIEW DATA COLLECTED

There are two examples presented in this appendix to show how the data was collected and organized. The first is part of a raw data set from a single interview. The second example shows some the interview statements collected under a single theme. This collection is from early in the analysis process, and the groups of statements are still separated by interview.

A.1. DATA FROM A SINGLE INTERVIEW

This is an example of a single interviews conducted with one of the company representatives who had participated in several recent system dynamics projects. It is presented in the form of the rough data notes taken during the interview itself.

Question # 1: What are your goals from introducing SD?
I had seen enough to see something powerful that no other methodology could provide. I have seen other fields and validated SD stuff on a personal basis. It's solid, feedback theory is well known

I was personally committed and began to apply system dynamics, increasing my understanding. I saw more applications, and it is critical to apply SD in areas that there are a lot of need for. With something new - look for areas with a lot of pain.... desperation (subset of hurting people) ready to take risk, the low hanging fruit...

We needed a powerful tool. In the chemical industry felt there is currently an oversupply, how do we deal with this. We can't grow forever.... there just can't be many new molecules. If the growth is not through innovative products, we very much need other angles. Everything looked gloomy - but company has very bright people. The limiting potential could be the management system. SD is good for looking at the management potential. Next few years are critical for this company.

We have already built a couple of success stories...
The first model was internally supported by my personal department - people worked on the project out of faith because there was no internal success story.

After the first test project, we then moved to a real success - done with another manager in an area with real PAIN

What has caused growth in the use of the methodology was a success story in a visible area of organization, change and conflict and uncertainty. Our reputations were on the line for this project.

The internal sponsors persistence is critical - access to a budget - having a budget - an outside consultant led through first model - no knowing what to do - to much information - tried to force-fit archetypes to the problem - should model first - before floundering too much - brought in an outside expert.

We followed a small models, heavy involvement with decision makers philosophy. I would have brought the outside expert in even without a budget, but ability to find money is critical....

If I was just in company, there would be no access to money to support a project like that - you need the contacts and credibility in the company -

Risk: What happens if it does not produce fruit - need a good long term batting average. Base to work on. Not career threatening

Question #1b: What attracted you to SD in the first place
Read the fifth discipline, in the back of book there was a reference to the modeling software "ithink." I was intrigued by systems thinking, but troubled by no validation methodology for the hypotheses generated through causal loop diagrams. I next called high performance systems and Peter Senge. Then I took the MIT summer course to learn about the computer modeling.

Question #2: How would you like to see the SD carried out? - what sort of process do you envision?

Right now the use of SD in my company is a skunk works operation. More authorized, but started out outside of functional areas. There is a management engineering services that should be doing this kind of internal consulting - they already do statistics and optimization models decision risk analysis. Those folks to date have been resistant - "we are the expects and we have not heard of it..."

where I think it should be:
business research function - they are responsible for finding and teaching new current methodologies for business strategy - they can facilitate the introduction process. They can act as facilitators right now and specifically focus on teaching tools to business managers. Process consulting standpoint.

Second possible area - there are four major segments of the company: business (strategy, markets, business issues), functional/manufacturing the products, core competencies - studying what we are good at from a technology perspective, and last arm is geographic - world business support, how to leverage across global market. There is a broad function in quality that spans these four areas - they could make internal system dynamics consultants - s

Process -
Vision: strongly feel that there will be very few people who will be doing the modeling - methodology is difficult and time consuming (most managers are older and not real good with the computer modeling - can't think that they would have the time to really become experts in a SD package)

Increasing awareness of systems thinking would come from mangers working on individual projects - took practice for me. Overtime, people would become familiar with the basic the philosophy of systems thinking and a single unit might have a senior staff person who could competently model. In our 15,000 people company, I picture ultimately having 5 or 6 people who could really know modeling. It would probably take 2-4 years of working on modeling projects to become competent.

Each study will have more at stake - (down the practice road) - more visibility and more risk. Until we get one or two real experts we will continue to use our outside expert to keep the team on track. Particularly for the development of causal loop diagrams and for quality assurance on the models - look over the model and give comments:

Why SD has not really taken off-
If purely in consulting mode (fixed budget schedule), when budget is gone, the consultant is gone, and there is pressure not to spend any more. He comes in, helps you, goes away. If the manager can't get the commitment that the model is valid and the model results need to be implement, he really needs to understand the model. The faith in the consultant has to move to an deep understanding of the model because the manager is going to take deep personal risk in implementing the results.

Introduction Steps -
Successes should follow a critical mass concept - important numbers of decision makers need to buy in. Quality management took a decade to become part of the formal process of our company. In the early days we did not understand quality management (very simple philosophy). As the field has advanced - meet the customer needs - low defects - meet the customers latent need - understand the customer that you see his needs before he does - the field as a whole is moving. In the beginning we tried to fill out all the forms - IE's have much training in QM. It didn't work, we just went through

the routines. Big questions around who is the customer, what is the process, etc. Took much pain to move to that point of view. But now, we can do the same sort of work in a couple of hours. I think that it has been a 10 year process of acceptance and internalization. Upper management made the personal investment of time and made resources available to the rest of the company. Trained people did facilitation for the company and we ultimately moving from going through the motions to doing what individually made sense. Took about 4 years to move from compliance to commitment.

SD should be applied when the need and awareness of the need is there. Timing has be about right. Need is pretty high.... If times were good, it would be more difficult

Meet with the folks that are focused on empowerment - need to have the other disciplines in place to really get at the real decision making. However, there is already an atmosphere of trust and openness in my group - not perfect. But you gotta have trust before the SD will work - people need to be up front about how decisions are REALLY made

Question #3: What are the organizational barriers that would stand in the way of a wider usage of system dynamics?

- data driven mentality - people struggle with it constantly
- need to be a conceptual (broad) thinkers
- managers have been promoted and rewarded for doing well in the manufacturing environment - who is able to keep the process running without letting new things in - need to move beyond this to look at the broad view - how decisions overall are made - this is not everyone -
- there might be 2-3 people in a team, functional managers, good people but one person that is essential is someone that has been thinking about the broad issues on a conceptual level

Need the high level commitment - someone who can implement the results, first or second in command. The head guy still makes the decision - what the boss says will happen - got to involve someone who is in the ear of the decision maker or the decision maker himself.

A.2. EXAMPLE OF EARLY "THEME" BASED DATA ORGANIZATION

The interviews were analyzed by dividing the stories by told each person into individual "statements". Each statement was treated as an independent piece of data. Overall common themes were identified and each piece of data was grouped according to the theme it supported. In the example presented in this section, the data from a few of the interviews conducted has been brought together under the theme, **The Role of System Dynamics.** At this stage of analysis, the statements are still grouped by their interview source - though the names have been separated from the statements already. Looking through this data, you can see that it contains opinions on what later became separated into modeling purposes, business roles, and the process of modeling.

After this stage, I identified the more specific themes running through the data, and the different statements was then synthesized into "common opinions" and "different perspectives."

Practitioner 1:
When they should use system dynamics:
He suggested that system dynamics is not a tool for day to day work.

System Dynamics as a problem identification tool:
SD can identify (how?) the critical business practices that Bose should be redesigning. Model output - five most important issues in the process that Bose should be considering to be objectives for the year.

There is currently a TQM planning process call Hoshin Kanri - perhaps there is a role for system dynamics within this planning process?

look at WV model of alternating between reality and planning - role of SD could be identify the high leverage possibilities and why....

Second possible "role":
For important issues - if long term 3 years plus and a year to make the decisions.
Takes a long time for organizations to change. -
What should be changing? Measurements? Training? Indicators? bottom line results?
Role: Monitoring and Measurement - can identify and set realistic goals that can be measured.

Explicit process for in-house modelers -
Bring in expert to layout model (roughly)
In-house modeler can work and put data into the layout of the model - bring it back to the expert modeler for periodic reviews. (Workshops?)

make sure that the problems being addressed is APPROPRIATE! climb up to the appropriate level.....

Company Representative 1:
1) Compress the time frame of expensive learning curve (time and space) allows one to learn from mistakes through the model and flight simulator.

2) Insight can be derived from the modeling process - look beyond events into cause and effect - Quantifiable experience, policy making can be less emotionally intense - de personify data.

Question to investigate:
What are the best ways to organize ourselves for projects?
Explore different structures - move from arguing about philosophies to look at the causes and consequences. Example: Core team approach vs structured approach.

Process:
Need a facilitator/ expert model builder to pull out the information (such as we did with previous project) An internal person could play this role, but would need the skills and perspective to ask the right questions, however, internal person would carry political baggage.

Case Study Interview 1:
Main challenge of System Dynamics -
Most business people do not believe in modeling. Outside of their experience and hens open to their suspicion.

big gap between people trying to understand what is going on and the people who are operating it. the problem with any model is constructing it, making it operational, making it part of the culture. More a problem than what technique you use.

number of data points already. Models that were good were developed and left on the table simply because no one related to it because it is outside of their experience. or it is so complex that they were not able to internalize it.

Spend as much time figuring out how to marry modeling to real processes could be a real contribution.

Gaps can be bridged between the technical knowledge and social knowledge.

How can any modeling be introduced into Bose. That can be a rich contribution. Nobody understands dynamics modeling. No matter what we do, it just sits on the side and doesn't get used.

For example: We need modeling because there are things outside our intuitive scope - simple minded things - control inventory - we make a plan - look one day - react to over inventory - reduce production - but nobody understands whether we should or shouldn't have inventory because at this time the models used are very simple static models. What don't we use a system dynamics model here? Should be a no brainer. The Gap. Trapped in the world of events.

Bridge the gap between what is clearly theoretically determinable and what people understand.

There are two classes of decisions being made here at Bose:
1) Incremental: Lets do more or less of this. Long term consequences could be modelable.
2) Break through decision: break into new areas - based on instinct - not sure that they are modeling.

While the biggest decisions are the ones that are worth looking at, it might be more fruitful to go down a level or two to where the people are actually piloting a system. Planners in general need more tools. Such as the inventory control system.

Take people from prado charts through to dynamic modeling. He feels is negative.

Company Representative 3:
People should be able to do it themselves.
Outside consultant? (expert?)
How would you set up SD?
Can't have a separate group doing system dynamics. People should be able to do it themselves. No third group.
In the short term - consultants run into internal barriers.
third group would also get the ax at the first budget crunch

System dynamics would allow the TQM analysis to move from static to dynamics.

Practitioner 2:
Project Selection Criteria
measurable results
significant business issue
potential payoff - opportunity for improvement is high
generic or recurring type of issue
dynamic complexity
- mental models systematically deficient
- leveragable (build theory, or there is already theory to build on)

Project team must be ready
- intuitive appreciation of dynamic complexity
- willingness to invest the time to learn
- committed to fundamental change
- understand the systemic change requires personal change
- must have the power to take action

Project team must be credible within organization (diffusion potential)

Practitioner 3:
Role: for decisions that have a dynamic characteristic
there is a continuum

SD for prediction ---->	SD for enlightened
complicated model	any problem that worries
difficult to use and understand	a manager
high value expectation	
model cost $150,00 to 1/2M	
requires expertise and validation	

What is system dynamics?
IT = process of system dynamics - CLD, reference modes, stocks and flows, policy creation and analysis, simulation

CLD = most cost effective (most personal modeling) - people feel like they have gotten a lot out of the process - communication, clarity of thought, systems perspective. This can take 1 day to several weeks of effort - most of the benefit is in the first few days.

modeling is expensive and time consuming - however, the focus is on counter-intuitive behavior - the loops do not always behave the way we might except from developing the causal loop diagrams.

along with the 10-20 how couldn't see the benefit from ST, around 50% of people will not see the use of engaging in a modeling process.
modeling will/should be done with a smaller sub-group from the group that developed the causal loop diagrams.

Process:
larger group for broad concepts
smaller groups for developing equations and building ownership with detailed model.
Attitude of the group should be a R&D project. Many of the insights generated might not directly relate to the "problem" itself and the ideal group should be able to learn from these also.

CLD - 4-5 real players, 8 maximum people
2 active people in the modeling
2-3 knowledge people around the area being investigated
when modeling, 3-4 real participants are all that can be handled - in this stage develop the stock and flow diagrams with the 4 people and the actual equations with only one other person.

Long term vision:
R&D with initial projects (project should continue as long as there is interest - start with a "real" issue such as product development)

need a continuous improvement mentality - knowledge comes from the journey as much as the destination
after reputation has been developed move towards problem solving
(in the beginning if you focus on problem solving you might link to the problem, if the problem fails you sink.)
Eventually institutionalize playful exploration
ultimately, require reports to have a loop analysis

Practitioner 4:
Modeling process should focus on the issue exploration through hexagons and causal loop diagrams.

Actual simulation model should be entered only very carefully,
(expensive and tend to implode)
only do if there still seems to be potential for learning and the answers cannot be generated intuitively.

ideally, you would like everyone in a company to be trained in "first-aid" systems thinking and only have a few very capable modelers who could act as facilitation guides to the process. See the notes or tapes for more details.

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