Systems Thinking and Wargaming

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Summary

Wargaming, in what may be called its modern form, has been around for well over 200 years.[1] Systems thinking and its more complex variant, systems dynamics, have been prominent techniques in management science since the late 1950s.[2] This paper explores the connections between these two powerful tools. It addresses the questions of how wargaming can support those who develop and use systems models, and how such systems models can, in turn, help those who design, control, and play in wargames.

These subjects are especially timely because today's theater commanders and their staffs are challenged to conduct—and assess the effectiveness of—"influence operations." The nature of these sorts of operations is always changing, and measures of their effectiveness are at best controversial and at worst, non-existent. Wargaming and systems thinking can help.

Our research and analysis of this subject leads us to conclude that wargames and wargaming techniques can help those who develop systems thinking models of operational and strategic interest. Similarly, systems thinking techniques can help wargame designers construct better wargames and explore techniques related to social and political interactions among nations and groups.

1. For a discussion of wargaming and its history, see Perla, Peter P. *The Art of Wargaming*. Naval Institute Press: Annapolis (1990)
2. See Forrester, Jay W.,"Industrial Dynamics—A Major Breakthrough for Decision Makers," *Harvard Business Review,* 36,4: 37–66 (1958), commonly accepted as the foundational document of systems thinking and systems dynamics.

This paper is intended to help analysts and wargamers understand systems thinking and how it relates to wargaming. Because many in our target audience have at least a basic grasp of the nature of wargaming, but less understanding of the nuances of systems thinking, the first half of the paper is in the form of an overview or tutorial about systems thinking and how to do it. We present several examples and some simple guidelines for how to apply systems thinking to building models of human organizations and processes.

The remainder of the paper explores the relationships among systems thinking and wargaming in practical terms. It describes how systems thinking can be used to enhance game design and execution, largely by providing a framework and approach for identifying important processes that a game must represent. A game is inherently a dynamic system model in which the game's players make decisions based on their pre-existing mental models, drawing on their internal experiences and understanding as well as both written and numerical databases.

In all but the simplest games, the goal is to examine not only player decision-making processes, but also the dynamic relationships between the various decisions players make. Understanding the dynamics of an interacting system can lead to the discovery of things that would not otherwise be revealed by a linear, prosaic, investigation of the topic. These "perversions" of the expected, which arise in games more frequently than in other forums, stem from several different feed forward and feedback loops, along with unspoken or unanticipated player actions. It is here that systems thinking models can provide unique support for gamers. By depicting clearly the interwoven network of relationships and interactions among complex elements of the environment, systems thinking models can provide wargamers a basis for structuring key elements of the game design and the game mechanics. Systems thinking models can also support both the players and controllers of a game during execution.

Wargaming and systems thinking are thus a matched pair of techniques, which, when used together, can help advance the state of the art of operational and strategic planning and assessment.

Systems thinking and wargaming

In this paper we discuss the application of wargames to systems thinking (ST) models, and ST to wargames. We want to explore how models of political, social, and cultural processes can be helpful to those designing, conducting, and playing in national security related decision-making games, as well as examine how games can be used to enhance or construct ST models.

In recent years there has been an increasing demand for tools that will allow operational and theater-level commanders to understand the human effects of their actions. Commanders routinely engage in actions designed to influence or affect behavior, and the results of those actions are often hard to measure (and even harder to predict). Without effective measures of success, it becomes difficult to assign a value to the various operational options, which complicates decisions about resource, attention, and policy trade-offs. Attempts have been made in the past by CNA and others to quantify the effects of engagement or other influence operations, with mixed success.[3]

Systems thinking models represent one approach to the problem of assessing the effects of various types of operations. Systems thinking models provide qualitative and structured representation of the relationships between key entities in the process that decision-makers are trying to influence, and so can help leaders and staffs understand better the effects of any action on the overall system. Likewise, ST models can be useful during preliminary planning for an operation. The ST model provides planners with a structured approach to evaluate and adjust various courses of action prior to implementation.

3. See, for example, David M. Rodney. *Naval Engagement Performance Plan* (U) Secret, CNA Research Memorandum D0005053.A1, Aug 2002; and Daniel Whiteneck and David Strauss. *Assessing Sea Shaping Capabilities,* CNA Research Memorandum D0014321.A2, Jul 2006

However, ST models face the same challenges that influence operations do; because they are heuristic and suggestive rather than direct and quantitative, it can be hard to determine whether they are accurately reflecting how things will work in the real world. Games, which are similar in their underlying intentions to ST models, may provide one avenue through which ST model developers could explore the validity and applicability of their models.

Likewise, because the political and other processes that can be simulated in ST models are often important elements of wargames, ST models may be able to contribute to wargaming. Game designers might learn from ST models, because the process of game design often involves a search for unidentified or unknown feedback loops, surprises, and unexpected relationships. Thus both ST model developers and game designers are interested in very similar process questions, and ST models use a more or less formal system to encode their developer's understanding of the processes they describe. Game designers could use ST models to help identify issues or relationships they hadn't yet thought of; at the same time ST model developers could use gaming techniques for the same purpose.

In this paper, we examine the relationship between ST models and games, and how both might benefit from interacting with the other.

Definitions

The following terms are important to understand in the context of this paper.

- **Games**.[4] There are many different types of games, but we are referring to games designed to illustrate or illuminate issues surrounding military action or involvement in national and international security issues. These games can range from large-scale games during which hundreds of players use sophisticated mathematical models to engage in very realistic simulations of the entire national security apparatus, or small, "table-top" games of dozens of players who may examine one aspect

4. Official DMSO definition: "A physical or mental competition in which the participants, called players, seek to achieve some objective within a given set of rules." See DoD Directive 5000.59M, *DoD Modeling and Simulation Glossary*, Jan 1998

of an issue. Most of these games have some way to "simulate" the environment for the players, ranging from sophisticated computer routines to a subject-matter expert (SME) sitting in the corner just making stuff up. Games are fundamentally about decision-making, which is what the players do. Games are closely related to narratives or stories, during which the facilitators or controllers and the players essentially act out a cooperatively created narrative. (These stories should not be confused with the idea of scenarios, which are the static settings for the games.)

- **Models and Simulations**.[5] The definitions of what is a model, what is a simulation, and what is a game can easily blur into each other. In this paper we are taking what might be considered a practical approach, using the terms to represent particular things that we need to do in game execution. Models, for our purposes, are structurally represented algorithms (such as ST models) that produce outputs that are a function of the inputs. Simulations are model aggregates that may be assembled from running one model under different conditions, running a model over a long time period, or running multiple models. Simulations attempt to represent in detail the workings of one or more real-world systems by generating aggregate outputs or behaviors based on the integration of component models. In this paper we are talking about models in the sense that they are practical algorithms that can be used to produce a certain output given a set of inputs. We are not generally concerned with simulations, other than their technical relation to systems dynamics models.

- **Systems Thinking Models**. ST models are essentially qualitative representations of the behavior of systems, constructed by showing the links between causes and effects of component elements of the system in ways that enable the user to explore the

5. Model: "A physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process." Simulation: "A method to implement a model over time." See DoD Directive 5000.59M, *DoD Modeling and Simulation Glossary*, Jan 1998

overall behavior of the system. They are constructed of "causal loops," which can be characterized as either reinforcing or balancing. Reinforcing loops show a relationship in which the increase in the size or value of one element tends to increase the size or value of connected elements of the system; balancing loops show a relationship in which the increase in the size or value of one element tends to decrease the size or value of connected elements of the system.

- **Systems Dynamics Models**. Systems dynamics (SD) models are most simply understood as extensions of qualitative ST models into quantitative forms, typically "solved" through computer simulation techniques, to relate changes in quantitative inputs to changes in quantitative outputs over time.

Our sample game

In this paper we describe elements of a notional game whose conceptual designs will provide consistent illustrations of our concepts. The game, which we call "Pacific Region Futures," examines the role of the U.S. Navy in the Pacific Region. The game's objectives are to understand the effect of various U.S. Navy actions, such as strategic communications, humanitarian or disaster relief, counterinsurgency or counterterrorism operations, and major warfighting operations. The goal of the game's players is to deter regional powers from becoming aggressive, while advancing U.S. interests in the region. The possible designs for this game could range from a card-driven board game,[6] to an intricate multi-player simulation involving civilian, economic, and other decision-makers. We chose this topic and region for our example because it relates to ongoing ST model-development efforts by the U.S. Naval War College, but our design and concepts in no way reflect current Navy strategy or thought.

6. For a description of such games, see CNA Research Memorandum CRM D0014752.A2/Final, *Wargaming Fourth-Generation Warfare*, by Peter P. Perla, Albert A. Nofi, and Michael C. Markowitz. Sep 2006

Throughout the paper we describe elements of different versions of this game in order to illustrate our points. These different versions also capture the breadth and scope of what we are talking about when we say “game”:

- Large-scale, national security decision-making game. This game would involve 100 or more players, have a large and politically challenging design team, and need to make many trade-offs in order to satisfy sponsor requirements. This game would be best illustrated by the “Title X games” conducted by the national service war colleges.
- Small-scale game focused on how combatant commands implement the strategy, but involving a large number of regional experts and players simulating the other countries in the region. This game would incorporate many of the softer PMESII (political, military, economic, social, information, and infrastructure) elements, such as economics, social, and political issues.
- A board game representing the play between the major powers (U.S., Japan, China, India, Indonesia, Russia) in the region. This game is intended to stand alone, with players following a standing set of rules to form alliances, conduct operations, and assess outcomes without the need for non-player controllers.

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Systems thinking

Forrester and the origins of systems thinking

In 1958, the Harvard Business review published an article by Jay W. Forrester titled "Industrial Dynamics—A Major Breakthrough for Decision Makers."[7] In this seminal article, Forrester integrated concepts derived from the field of feedback control with the techniques of computer simulation to describe an approach to understanding how systems change through time. The general approach of thinking about systems that Forrester introduced has come to be described as Systems Thinking; the implementation of mathematical models and computer simulations to quantify effects and outcomes of systems behavior has come to be described as Systems Dynamics. This paper focuses on Systems Thinking, discussing Systems Dynamics primarily to place Systems Thinking in the broader context.

Not long after Forrester's paper kicked off these ideas, the System Dynamics Group at the Sloan School of Management at MIT began to develop what has come to be called "flight simulators for management." One of the earliest of these simulators, the Beer Game, grew directly out of "Forrester's research on industrial dynamics. It has been played all over the world by thousands of people ranging from high school students to chief executive officers and government officials."[8] Games and systems thinking have been joined at the hip almost from the start.

7. Forrester, Jay W., "Industrial Dynamics—A Major Breakthrough for Decision Makers," *Harvard Business Review,* 36,4: 37–66. (1958)

8. Sterman, John D. "Teaching Takes Off: Flight Simulators for Management Education," *OR/MS Today,* October 1992, 40–44 Available at http://web.mit.edu/jsterman/www/SDG/beergame.html

At its heart, systems thinking "combines the theory, methods, and philosophy needed to analyze the behavior of systems in not only management, but also in environmental change, politics, economic behavior, medicine, engineering, and other fields."[9] The key idea of systems thinking and systems dynamics is its focus on understanding and influencing change over time; hence "dynamics."

Some basic concepts of systems models

As with any model of real-world phenomena, a systems-thinking or systems-dynamics model must be grounded in as thorough an understanding of the situation and behaviors as it seeks to represent. That understanding is obtained both from hard data and from what Forrester called "the wealth of information that people possess in their heads. The mental database is a rich source of information about the parts of a system, about the information available at different points in a system, and about the policies being followed in decision making." This last point is a critical one for wargame designers, and one frequently overlooked because of the fact that "management and social sciences have in the past unduly restricted themselves to measured data and have neglected the far richer and more informative body of information that exists in the knowledge and experience of those in the active working world."[10]

In the same paper, Forrester also identified the direct link between systems thinking and wargame design. "The feedback structure of an organization can dominate decision making far beyond the realization of people in that system. By a feedback structure, I mean a setting where existing conditions lead to decisions that cause changes in the surrounding conditions, that influence later decisions. That is the setting in which all our actions take place."[11]

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9. Forrester, Jay W. "Systems Dynamics and the Lessons of 35 Years," a chapter from *The Systemic Basis of Policy Making in the 1990s*. Kenyon B. DeGreene, ed. Sloan School of Management, MIT, Boston, MA, (1991). Available at http://web.mit.edu/jsterman/www/SDG/beergame.html. Hereafter Forrester (1991). Quotation is from p. 5.

10. Forrester (1991), p. 5

11. Forrester (1991), pp. 7 – 8

That is also the setting in which wargames take place; players react to their environment to make the decisions that change that environment.

To construct his models and analyses, Forrester had to acquire and make operational an intimate knowledge of the connections among organizational structure, what he called "policy," and the behavior of both individuals and the system as a whole. It is worth letting him describe that process in detail.

> Information comes primarily from interviewing people in the company about how they make decisions at their individual operating points. Statements describing the basis for decisions are the rules or policies governing action. As I use the term "policy," it represents all the reasons for action, not just formal written policy. These interviews are extensive and penetrating. There might be several sessions with each of many individuals. The discussions range widely from normal operations, to what was done in various kinds of past crises, what is in the self interest of the individual, where are the influential power centers in the organization, what would be done in various hypothetical situations that have never happened, and what is being done to help in solving the serious problems facing the company.

Once the data are in hand, the process of constructing the model begins. From what resembles a classic case study, Forrester proceeds to give life to the static description of the target organization by embodying it in a mathematical model, usually taking the form of a computer simulation.

"Just as with the operation of a chemical plant, only computer simulations methods are capable of revealing the behavior implicit in the structure that can be built from knowledge about the many local decision-making individuals and how they are connected."[12]

This integration of simulation and the case-study method addresses the crucial weakness of the latter—"The description of a case captures policies and relationships that together describe a system so

12. Forrester (1991), p. 10

complex that it cannot be reliably analyzed by discussion and intuition. Such attempts often draw the wrong dynamic conclusions and fail to reveal why corporations in apparently similar situations can behave so differently."[13]

Based on his experience with the dynamics of feedback systems, Forrester created simulations of the operation of social and economic systems embodying the principles of feedback processes to represent the engine of change. But the complexity and non-linearity of such systems requires the use of computer techniques if you are going to see and begin to understand the behavior of the system.

As is the case with models of all types, and with wargames in particular, the "ultimate success of a system dynamics investigation depends on a clear initial identification of an important purpose and objective."[14] He continues, "In general, influential system dynamics projects are those that change the way people think about a system. … If a model is to have impact, it must couple to the concerns of a target audience. Successful modeling should start by identifying the target audience for the model." Just as is the case with successful wargames.

One of Forrester's principal insights and arguments for the use of systems thinking is that, "Complex systems defy intuitive solutions."[15] In particular, human intuition about the expected behavior of complex systems is usually just plain wrong. We jump from tangible and reliable understanding of the structures, policies, and parameters of a system to an intuitive and often faulty assessment of the behaviors those structures, policies, and parameters imply. Using the systems-thinking approach "separates consideration of underlying assumptions (structure, policies, and parameters) from the implied behavior.

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13. Forrester (1991), p. 13

14. Forrester (1991), p. 15; compare this statement to the following: "sponsors, designers, and game analysts must work together … not only [to] identify the game's objectives, but also [to] define how and in what ways the game will help meet those objectives." From Perla, Peter P. *The Art of Wargaming*. Naval Institute Press: Annapolis (1990), p. 193

15. Forrester (1991), p. 15

By considering assumptions independently from resulting behavior, there is less inclination for people to differ on assumptions, with which they actually can agree, merely because they initially disagree with the dynamic conclusions that might follow."[16]

Forrester argues that the human imagination is more likely to err in its assessment of the expected behavior of the system based on its known or observed structure than the model of the system will fail to produce its actual behavior. Human mental models are both the problem and the target of systems dynamics. For Forrester, "a systems dynamics model, if it is to be effective, must communicate with and modify the prior mental models. Only people's beliefs, that is, their mental models, will determine action."[17]

But if one is to affect the mental models of most people, smaller is almost always a better choice than larger. In fact, Forrester explicitly links such small models to games: "Simple models used as interactive games, such as one demonstrating the economic long wave, or Kondratieff cycle (Sterman and Meadows, 1985), can also create a dramatic impact as they reveal unexpected implications of existing mental models."[18] Of course, simple models may not help in understanding the more complex issues that only larger and more complex models can tackle. Similarly, small games are easier to design and manage than larger games, but may not create the types of complex interactions you are most interested in exploring.

Building systems-thinking models

As a result of his fundamental perspective about feedback, it is hardly surprising that Forrester built his system of thinking on the notion of loops. Basic among these are feedback loops, also called causal loops.

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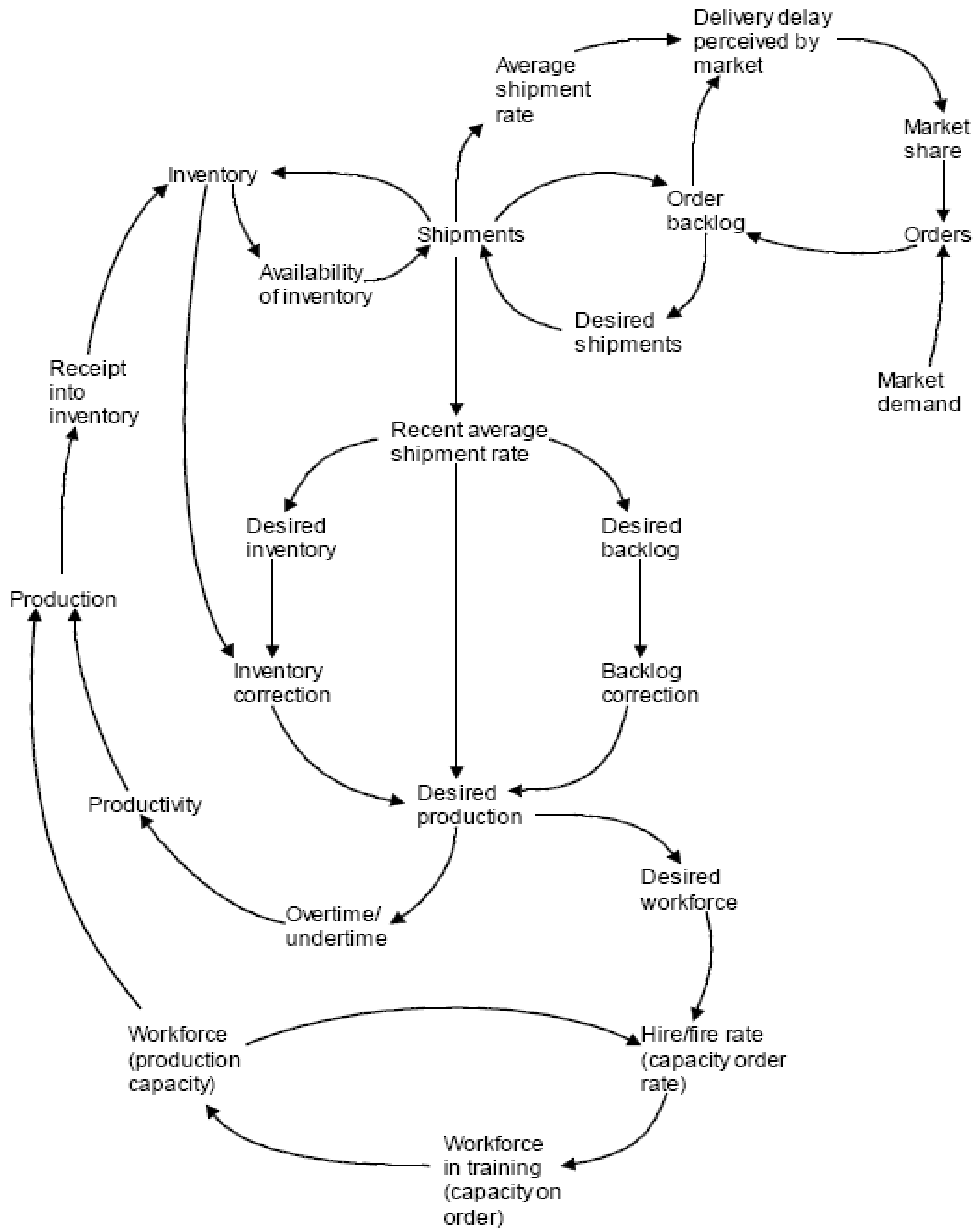
16. Forrester (1991), pp 15 – 16
17. Forrester (1991), pp. 19 – 20
18. Forreseter (1991), p. 20. The reference is to Sterman, John D., and Dennis Meadows, "STRATEGEM-2: A Microcomputer Simulation Game of the Kondratiev Cycle," *Simulation and Games,* Vol. 16, No. 2, 1985, pp. 174 – 202

Typically, practitioners of systems thinking use diagrams to illustrate the relationships represented by these loops. Although we will later describe the more complex models and behaviors more typically associated with systems-dynamics simulations, our primary emphasis is on the relatively cleaner systems-thinking models, which are often precursors to these more complex simulations.

Loop diagrams and their characteristic behaviors

Consider the diagram in figure 1, which represents the feedback structure of a basic production process. We show the elements of the process in words. For example, in the upper left corner of the diagram is the element of the process we have labeled Inventory. The arrows show that one element of the process influences another, and are called the causal links between the elements. For example, inventory influences Availability of Inventory and the latter influences Shipments. Shipments, in turn, influences Inventory, thus closing the loop and showing that Inventory actually influences itself through those intermediate steps, thus creating a feedback relationship. The loop from Inventory to Availability of Inventory to Shipments and then back to Inventory is an example of a feedback loop.

Figure 1. Feedback structure of a basic production process[a]

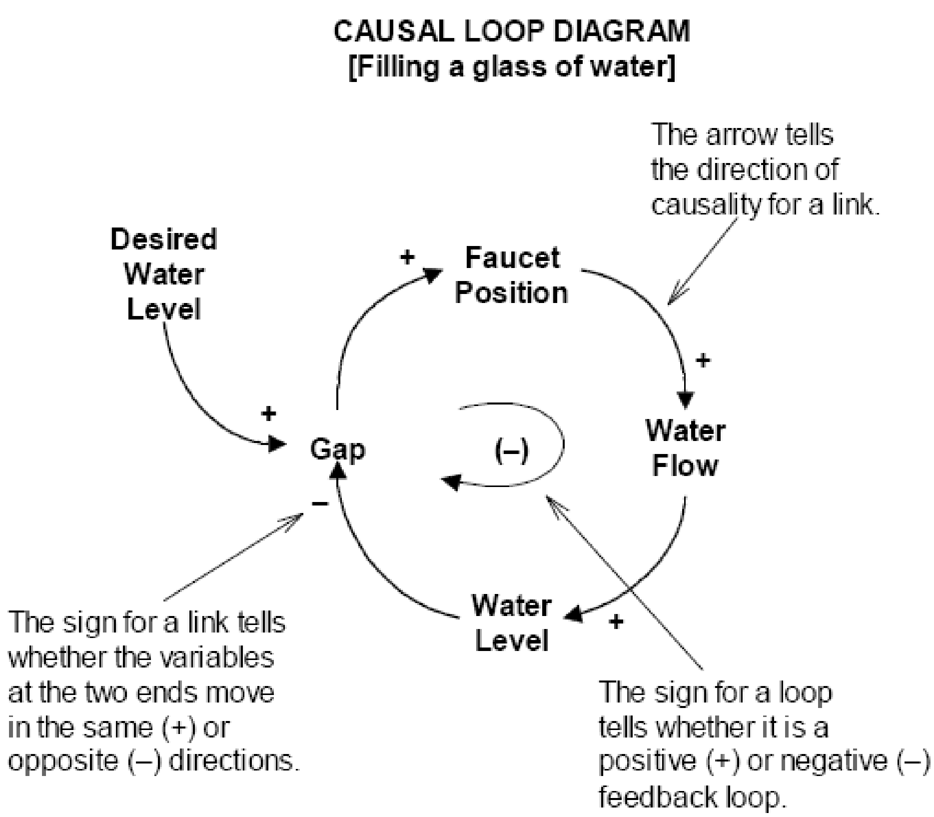


a. From Kirkwood, Craig W. *Systems Dynamics Methods: A Quick Introduction*. On-line version, 1998. Available at http://www.public.asu.edu/~kirkwood/sysdyn/SDIntro/SDIntro.htm. p. 6

Systems thinking adds a second layer to a basic loop diagram to include more information and facilitate more detailed analysis. This layer annotates the causal links with either positive (+) or negative (-) signs. A positive sign linking element A with element B indicates that either A adds to B or that a change in A produces a change in B in the same direction; that is, increasing A will increase B or decreasing A will decrease B. A negative sign linking indicates that either A subtracts from B or that a change in A produces a change in B in the opposite direction; that is, increasing A will decrease B or decreasing A will increase B.

Figure 2 shows a simple causal loop diagram for the process of filling a glass with water.

Figure 2. Notation for causal loop diagrams[a]

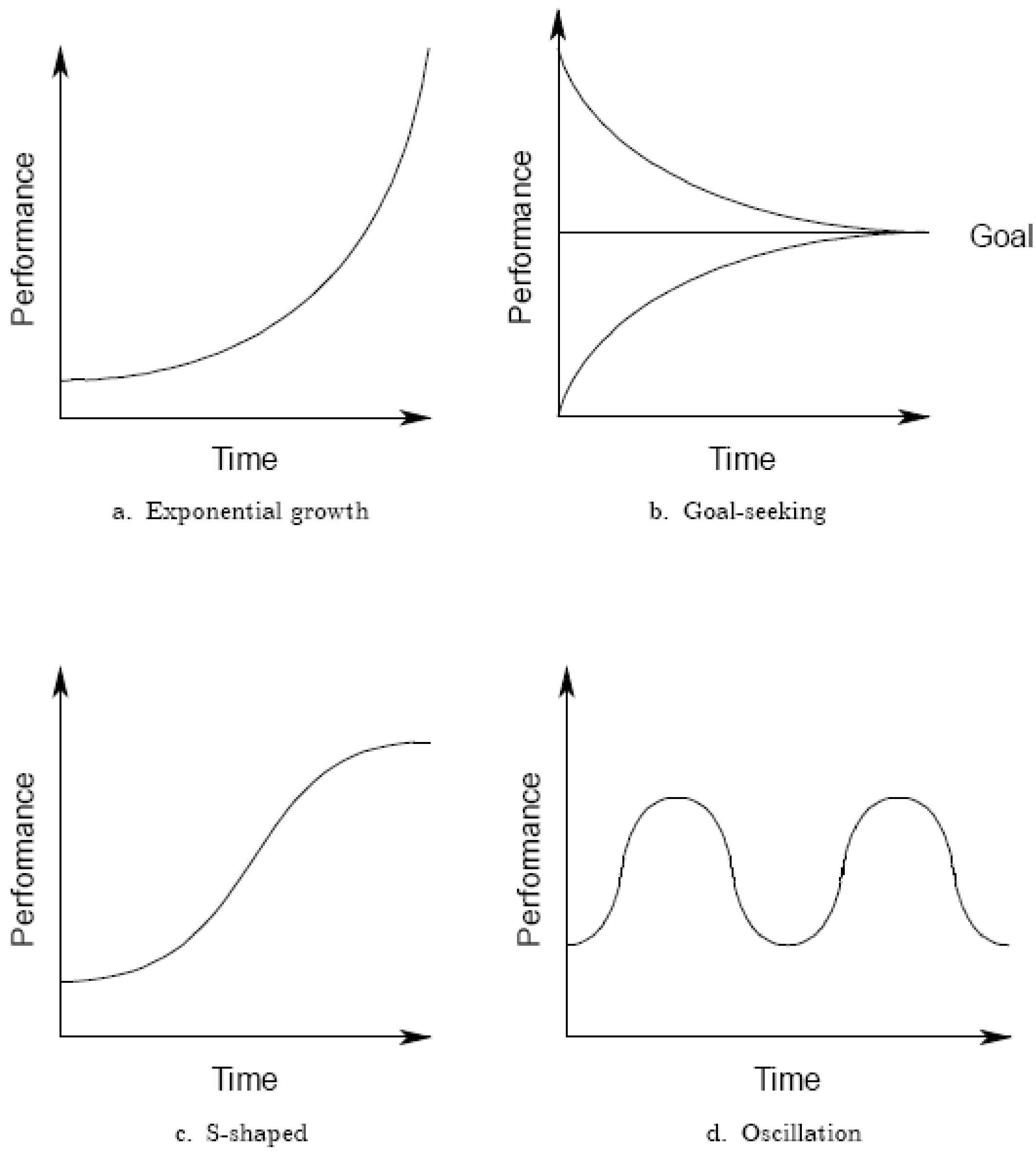


a. From Kirkwood (1998), p. 8

Increasing the faucet position increases the water flow, which in turn increases the water level in the glass. The "Gap" element represents an assessment of the difference between the level of water in the glass and the desired level. So, increasing the water level decreases the gap, hence the negative sign on that link. Finally, a larger gap presumably leads to increasing the faucet position. The final link in the loop connects "Desired Water Level" and "Gap"; this is also a positive link. Another convention is the characterization of the entire closed loop itself by assigning it its own positive or negative sign. This overall loop sign will be positive if there is an even number of negative links, and negative if there is an odd number of negative links. Thus our example shows a negative loop sign. Positive loops are called "Reinforcing" loops and are sometimes indicated by an "R" rather than a +. Negative loops are called "Balancing" loops and are sometimes labeled with a "B."

Reinforcing loops get their name from the fact that introducing a change into the system drives the system in the direction of that change. Such a reinforcing loop can produce the pattern of behavior we associate with exponential growth (See figure 3a.). The balancing loop seeks to hit a target or goal, as in the case of the water-filling example (figure 3b). (Though we do not have a loop indicating that we should pour off the excess water if we overfill the glass!).

Figure 3. Basic patterns of systems behavior[a]



a. Kirkwood (1998), p. 4

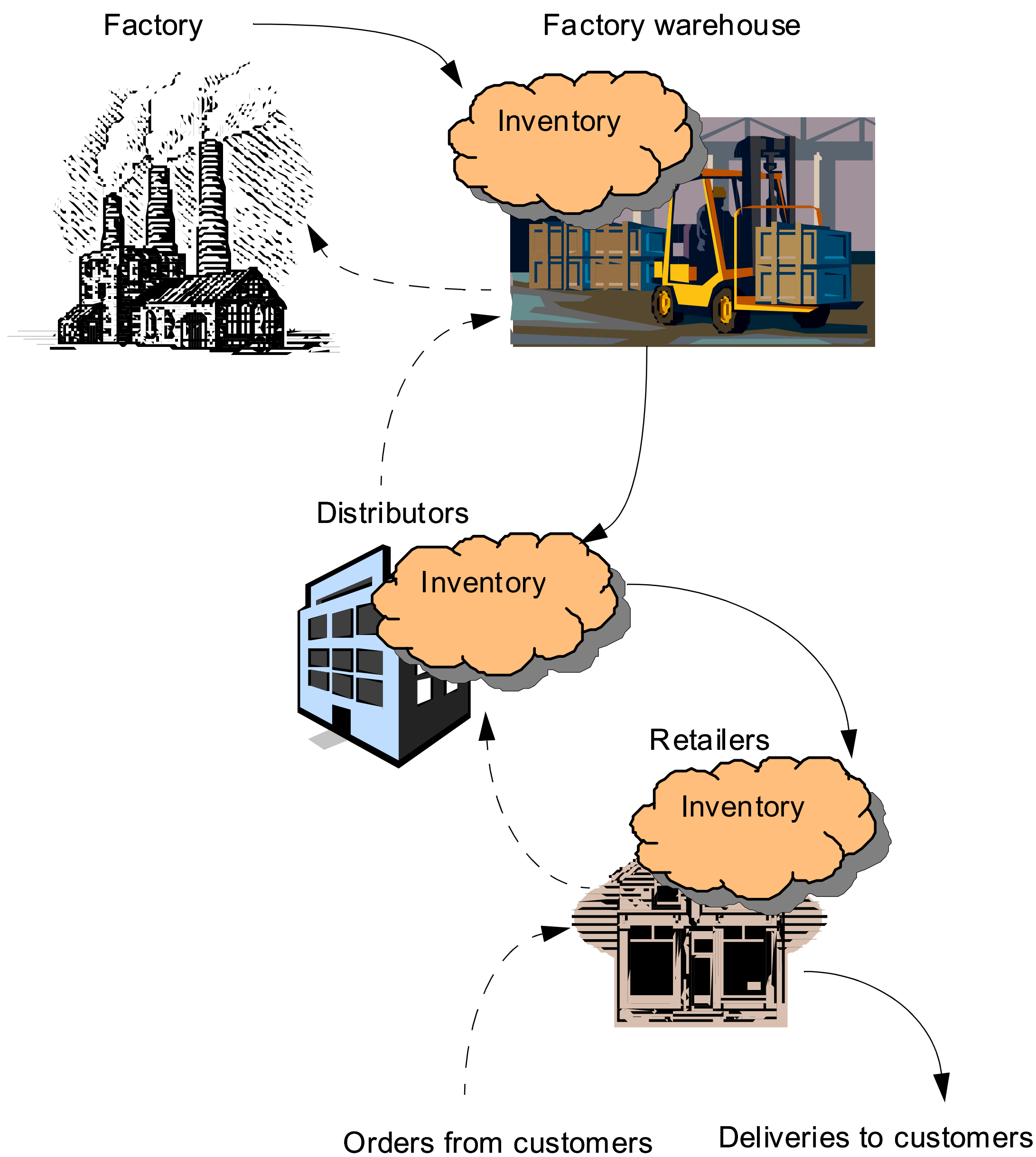
Goal-seeking behavior can be either good or bad—it can provide a stable environment, but also can resist necessary change. The more complex patterns of behavior illustrated in figures 3c and 3d require more complex loop systems. In all cases, however, the systems-thinking models of interest to us in this current effort retain their simple syntax of relationships—one node's influence on a connected node is either “the same as” or “the opposite” direction.

The s-shaped behavior pattern (figure 3c) can arise from a combination of positive and negative loops when, for example, a positive loop triggers initial exponential growth but after some delay a balancing loop takes hold and drives the system to goal-seeking behavior. Indeed, most processes cannot continue to grow exponentially forever, and some sort of balancing loop will usually come into play. A negative feedback loop coupled with a substantial delay in one or more of its links can produce an oscillatory behavior as in figure 3d.

This sort of behavior figures prominently in one of Forrester's principal examples in his original article—that of a multi-level production and distribution system (see figure 4.) Such systems can display this oscillatory behavior “because of delays in conveying information about the actual customer demand for a product to the manufacturing facility. Because of these delays, production continues long after enough product has been manufactured to meet demand. The production is cut back far below what is needed to replace items that are sold while the excess inventory in the system is worked off. This cycle can continue indefinitely.” [19]

19. Kirkwood (1998), p. 11

Figure 4. Multi-level production-distribution system[a]



a. Based on Forrester (1958), p. 41

How to draw causal loop diagrams

The basic ideas of systems thinking as described in the preceding material are fairly straightforward. Putting them into practice is another matter—especially when you progress from the basic loop diagrams characteristic of Systems Thinking to the complex simulations characteristic of Systems Dynamics, which often uses high-order differential equations to quantify in detail the performance of a system. If designers want to get that serious about building systems dynamics models, they should consult an expert or, at the very least, a comprehensive advanced text.[20] For our purposes in the current study, however, some basic hints will be of use in understanding how the process of systems-thinking modeling relates to and can apply to wargame design. These ideas are drawn from Kirkwood (1998) and the guidelines he used, which in turn stem from Richardson and Pugh (1981) and Kim (1992).[21]

The preliminary thinking involves assessing which events are important for understanding the behavior of the system of interest. For example, sales may be decreasing. Using these events, try to characterize the patterns of behavior over time for the items of interest—do they exhibit exponential growth, or oscillation, or an s-shaped pattern? The patterns of behavior will indicate the general shape of the main causal loops at play, in the manner described earlier. For example, an s-shaped sales performance may indicate that a balancing loop has come to dominate initial exponential growth. Why is this the case? This question can become a starting point for designing your causal loop diagram to explain the observed behavior of the system. Designers can proceed from this starting point by following Kirkwood's seven hints.[22]

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20. For example, an extensive and relatively modern text is John D. Sterman's *Business Dynamics: Systems Thinking and Modeling for a Complex World.* McGraw-Hill, New York, 2000.

21. D. H. Kim, "Toolbox: Guidelines for Drawing Causal Loop Diagrams," *The Systems Thinker,* Vol. 3, No. 1, pp. 5 – 6 (February 1992) and G. P. Richardson and A. L. Pugh III, *Introduction to Systems Dynamics Modeling with DYNAMO,* Productivity Press, Cambridge, Massachusetts, 1981.

22. The hints are paraphrases of those in Kirkwood (1998) pp. 13 – 14

1. Think of the elements of the loop as variables whose values may go either up or down. One does not have to be able to determine a scale for these values, just that they can increase and decrease. In particular:

   - Use nouns or noun phrases to define the elements, not verbs. The elements are things, the links are the actions.

   - The definition of the element should clearly indicate which way is up. For example, use "acceptance of uncertainty" not "attitude toward uncertainty."

   - It is usually clearer if your choice of name implies an increase in value is good or preferable. For example, "survivability" rather than "vulnerability."

   - Causal links should imply just that, causation, not merely the sequence in which events occur. A positive link from element A to element B means that A increases B, not that A occurs before B.

2. As you define links, think about possible unexpected side effects beyond those you are defining, and decide whether you should add links to represent those side effects.

3. Negative feedback loops usually involve a goal. Explicitly show both the goal and the "gap" that drives the loop toward the goal.

4. A difference between the actual state of a process and its perceived state can often be important to explaining patterns of behavior. It may be important to include loop elements for both actual and perceived values. It is often the case that there are delays before the actual state can be perceived. For example, the results of a combat engagement can often be reported incorrectly or incompletely at first, with the actual outcomes becoming known to higher commanders only later.

5. Short-term and long-term consequences of actions may differ and so may need to be distinguished with distinct loops. For example, the short-term effects of a kinetic strike on a terrorist safe house may be political euphoria, while the long-term effects may be increased recruitment for the terrorist organization.

6. If you find yourself constructing elaborate explanations for the link between two elements, you may need to add intermediate elements between them to show more clearly what is going on.
7. Finally, keep it simple, or at least as simple as possible given that you are following all the other hints above! Remember that the goal of the diagram is to show those aspects of the feedback's structure that lead to the observed pattern of behavior, not to describe every detail of the real processes. This advice, perhaps more than any other, is something that a wargame designer knows—or should know. Failing to heed it will cause a systems-thinking model or a wargame to go off the rails faster than just about anything else.

Stocks, flows and information

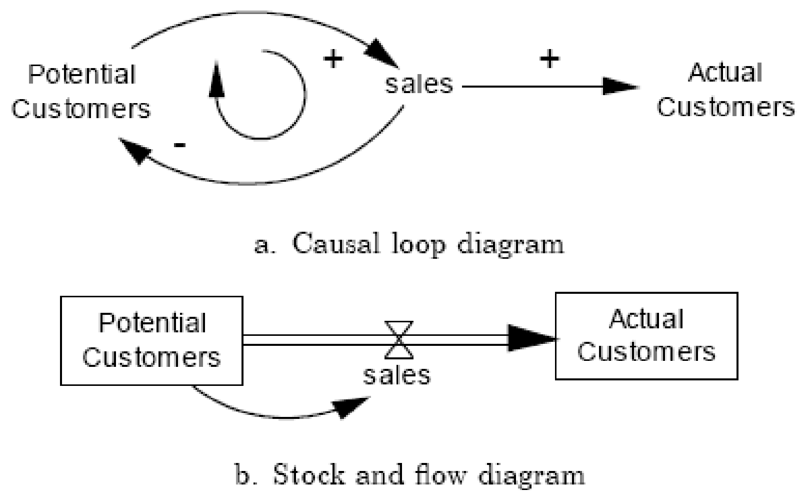
Creating causal loops is only the first major step in the process of modeling the behavior of complex systems. Another powerful tool in the systems-thinking arsenal is called a stock and flow diagram. Understanding the use of this technique is critically important because, as Kirkwood notes, it "provides a general way to graphically characterize any business process. … It is a remarkable fact that all such processes can be characterized in terms of variables of two types, stocks (levels, accumulations) and flows (rates)."[23] Although our ultimate modeling objectives in the current effort are more accurately described as political-military processes than business processes, the similarities are close enough for many purposes that understanding stock and flow processes will take us a long way toward understanding many aspects of political-military modeling as well.

Consider, for example, figure 5, taken from Kirkwood. Figure 5a shows a causal loop diagram for an advertising process related to any sort of durable good, such as a toaster. The pool of potential buyers of our toaster is converted into actual customers through the process of selling them a toaster. This is a negative feedback loop: an increase in potential customers can be expected to lead to an increase in sales (our toasters actually work and are good value) but increased sales

23. Kirkwood (1998), p. 17

reduce the number of potential customers by converting them into actual customers. Thus, the positive arrow from potential customers to sales is balanced by the negative arrow from sales to potential customers, creating a negative feedback loop with the goal of reducing potential customers to zero by converting them all to actual customers.

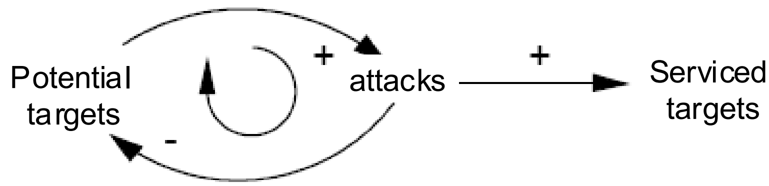
Figure 5. Example of causal loop and stock and flow[a]



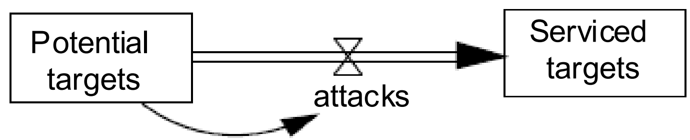
a. Kirkwood (1998), p. 16

Now consider figure 6. It has the same structure as figure 5, but we have applied it to a military targeting process. Potential targets replace potential customers, and serviced (i.e., destroyed) targets replace actual customers. Assuming that we have an infinite supply of weapons and a set of targeting sensors and communications that allows us to find and attack the targets at will, the relationships are the same as for the toaster makers. Our goal is to convert all the potential targets into dead ones.

Figure 6. Targeting as a stock and flow problem



a. Causal loop diagram



b. Stock and flow diagram

The causal loop diagrams alone are not all that interesting. Their principal implication is that sales (or attacks) must eventually go to zero as the pool of potential customers (targets) reaches zero. But it does not tell us anything about the rate at which this process runs. Is it a matter of days or weeks, or one of months and years?

The lower half of each of the figures introduces a new set of notations by which we can represent this sort of process. The variables in these diagrams are either stocks or flows. Stocks are depicted in the rectangles; Potential/Actual Customers and Potential/Serviced Targets are the stock (or level or accumulation) variables. The flow variables are depicted as a “bow tie” or “butterfly valve” symbol (two stacked triangles) overlaying a broad arrow; sales and attacks are the flow (or rate) variables. You can think of the arrow as a pipe along which the stocks flow from one box (or container) to the other, controlled by the valve symbol. “A stock is an accumulation of something, and a flow is the movement or flow of that 'something' from one stock to another.”[24]

24. Kirkwood (1998), p. 17

The third element of the b figures above is the curved arrow from Potential Customers to sales and Potential Targets to attacks. This arrow, not the same type of arrow as that used to represent the path of the flow, indicates that in some way information about the stock is influencing the flow. That is, information about Potential Targets influences attacks. What's more, the lack of a similar arrow tying Serviced Targets to attacks means that information about the value of the Serviced Targets stock does not affect the value of the attacks flow. Kirkwood said that "The creation, control, and distribution of information is a central activity of business management"[25]—and of military leadership.

Kirkwood's comments about the critical importance of information to modern business management apply just as well to the military's insistence on the critical importance of "information warfare."

> In a traditional hierarchical business organization, it can be argued that the primary role of much of middle management is to pass information up the hierarchy and orders down. This structure was required in pre-computer days by the magnitude of the communications problem in a large organization. With the current widespread availability of inexpensive computer-based analysis and communications systems, this large, expensive, and slow system for transmitting information is no longer adequate to retain competitive advantage…and thus the set of information links is a central component in most models of business processes oriented toward improving these processes.[26]

But information is not a tangible and physical entity like toasters or even computer parts. There is no law of conservation of information limiting its flow from one place to only one other place at a time. Modern computer and communications systems enable information to flow rapidly to and among a large number of locations. Sometimes, however, the information morphs from one form to another as it moves, creating new problems of distortion and distraction. "Doing large-scale experimentation by making *ad hoc* changes to a crucial

25. Kirkwood (1998), p. 19

26. Kirkwood (1998), p. 19

aspect of an organization like the information links can be dangerous."[27] Analysis using systems thinking, systems dynamics, wargames, and other tools becomes even more critical as a means of evaluating the potential effects of such changes in information and information links, especially in the military environment.

The importance of information and its flow through its own sub-network of causal loops and stock and flow diagrams makes it clear that accurate modeling of even relatively simple business processes must account for the intersection of information networks with the other, more physical, networks involved in the representation of the processes of interest. Sometimes these information elements are really just simple state information. For example, in our examples above, we included the information about the level of the potential customers or potential targets, which would affect the flow control of sales or attacks. In more realistic cases, however, the information flows to and from decision-makers, either human or machine. So let's take a look at some notions about how systems models might represent decision processes, particularly those in which humans cast the deciding votes.

Representing decision processes in systems models

Our discussion of systems-thinking and systems-dynamics models has not mentioned explicitly the role of human decision-making in the simulations used to embody and experiment with such models. Because wargames are quintessentially about human decision-making, it is important to say a few words here about how systems thinking and systems dynamics can incorporate human decisions into their models.

First off, we are going to rule out man-in-the-loop models that include human decision-making as part of the discussion of systems models. What we will call *pure systems models* incorporate human decision making processes by coding the parameters of the decisions and the options into the causal loops and stock-and-flow diagrams that

27. Kirkwood (1998), p. 19

embody the systems-thinking models. For systems-dynamics models, they also can encode decision-making into the models' quantitative computer routines. Actual human decision-makers assume active, real-time roles in games, but not in the systems models. As we will discuss later, we can use the pure models to help inform games, and we can use games to help inform the pure models.

The critical considerations that persuade users of pure systems models to incorporate machine models of human decision making stem from the fact that "research results strongly support the conclusion that human decision-making is neither particularly complex nor particularly effective. ... It is possible to model human decision making with relatively simple models, and it is also possible to improve on unaided human decision-making with systematic decision policies."[28] Of course, it is the latter that the models most require. Unlike the more intuitive human, the decision-making computer routine must define some sort of systematic policy on which it will base its choices. But there is a bit of a trap here—the more well-defined the systematic policy is, the less likely it will be to reflect actual human decision processes. This is not necessarily a problem when the purpose of the model and its use is to find ways to improve existing processes largely under our own control. When the environment includes potential competition and conflict among other human agents, such as is the case in wargames, a too rational and systematic representation of human decisions may prove to be misleading, precisely because such representations are unrealistic depictions of actual human decision-making.

There is a large body of research in psychology and, of all things, epistemology, which indicates the weakness of the predictive capacity of even so-called experts.[29] Among other things, this body of work

28. Kirkwood (1998), p. 83

29. See, for example, Michael A. Bishop and J. D. Trout. *Epistemology and the Psychology of Human Judgment.* New York: Oxford University Press U.S., 2005 and Reid Hastie and Robyn M. Dawes. *Rational Choice in an Uncertain World: The Psychology of Judgment and Decision Making.* Thousand Oaks, CA: Sage Publications Inc., 1988. See also Kirkwood (1998) chapter 7, pp. 83 – 101

argues persuasively that simple linear models using random parameter values often outperform human experts, but that human experts seldom return the favor. This allows practitioners of systems dynamics to incorporate even simple quantitative models of decision-making into their larger simulations with some assurance that they are doing no worse in their output measures than if they represented actual human behavior. "However, this research also points out that experts play a key role in developing such models: They are needed to identify the key variables to incorporate into a model."[30] As we will discuss later, it is here that wargaming can be an especially valuable adjunct to systems models. And vice versa.

Contrasting systems-thinking and systems-dynamics models

The earlier sections show some small examples of parts of the systems-thinking and, to a lesser extent, systems-dynamics modeling processes. Before proceeding to a detailed discussion of wargaming, we will conclude this part of the paper by presenting some more extended examples of such models, and a more careful distinction between the two. We begin by outlining a classic *systems-dynamics* model that occurs in the environment of commercial businesses. We will follow up this discussion by describing an example of a political-military *systems-thinking* model created by Professor Stephen Downes-Martin of the Naval War College.[31] This latter model is one of the motivators for this paper, and we will revisit it at the end of the paper as a vehicle for integrating our thinking about how wargames and systems-thinking models can work together. Finally, we conclude our examples by discussing the famous Beer Game model.

30. Kirkwood (1998), p. 86

31. Stephen Downes-Martin. *Measures of Effectiveness for Strategic and Operational Objectives using Systems Thinking*, Briefing, 20 Aug 2008

A systems-dynamics example: the Bass diffusion model

The Bass diffusion model is named for its originator Frank Bass.

The Bass model is an attempt to represent the dynamics that drive the diffusion of innovative ideas throughout an industry or product category. It is a systems-dynamics model because it takes the underlying systems-thinking model, represented by causal-loop diagrams and a simple stock-and-flow relationship, and quantifies that model in a set of mathematical relationships.[32] These relationships are derived from an additional set of mathematical assumptions concerning the nature of the positive or negative cause-and-effect links postulated by the underlying systems-thinking model. The Bass diffusion model "has become one of the most popular models for new product growth and is widely used in marketing, strategy, management of technology, and other fields,"[33] according to Sterman.

Previous models of diffusion suffered from a real problem: most of them assumed that a positive feedback system evolved from an installed base of existing product that was already owned by consumers. When such an installed base was actually non-existent (as might be the case for a new product such as cable television or the first microcomputers), those models suffered because they had an equilibrium point at a zero level of installed base, ensuring that nothing could happen without some outside force—that is, a force outside the scope of the model—acting on the system. Bass introduced such an outside force explicitly in his model, by "assuming that potential adopters become aware of the innovation through external information sources whose magnitude and persuasiveness are roughly constant over time." [34]

32. See Bass, Frank M., "A New Product Growth Model for Consumer Durables," *Management Science*, Vol. 15, pp. 215 – 227, 1969. Reprint version available online at http://www.jstor.org/stable/pdfplus/30046153.pdf, from *Management Science*, Vol. 50, No. 12 "Ten Most Influential Titles of Management Sciences First Fifty Years," (Dec. 2004), pp. 1825 – 1832. The discussion of this model is largely taken from Sterman (2000), pp. 332 – 335.

33. Sterman (2000), p. 332

34. Sterman (2000), p. 332

Bass's original work did not use the techniques of systems dynamics explicitly. Instead, he derived his model by, in essence, characterizing the "literary theory"[35]of those such as Rogers, and the mathematical contagion models used in epidemiology.[36]

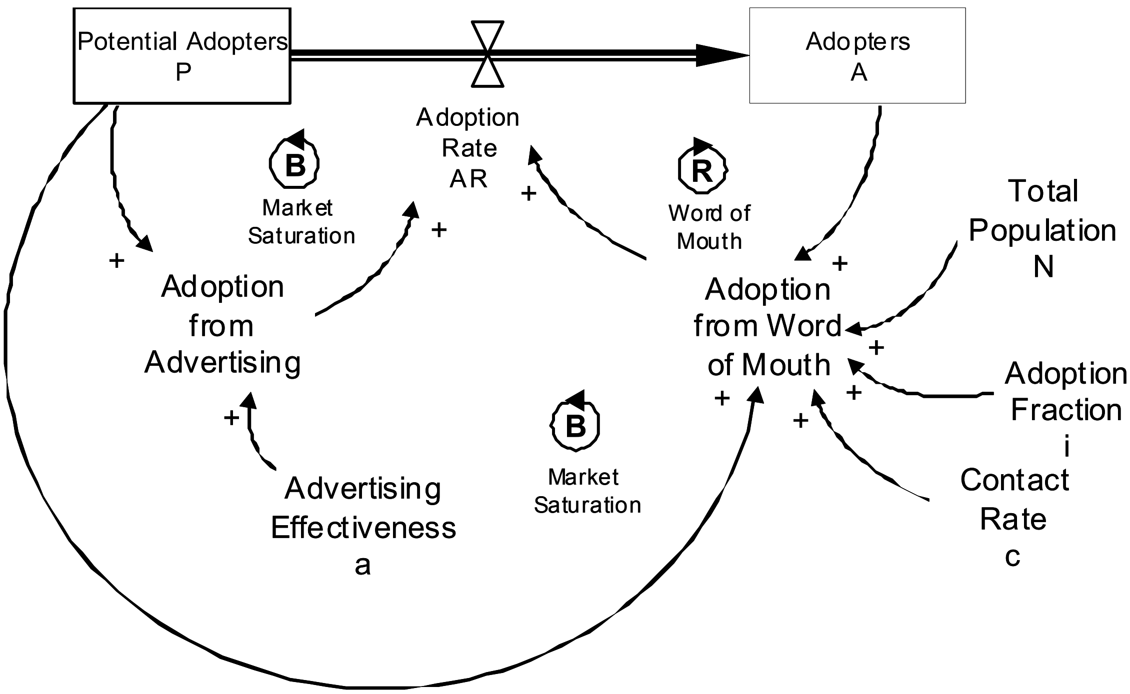
Figure 7 represents Sterman's version of the Bass model, in which the external source is presumed to be the effects of advertising. It also includes a source of positive feedback, here characterized as "word of mouth," implying both "social exposure and imitation."[37] This version of Bass's model postulates that the total adoption rate (AR) is composed of two principal parts: the rate based on external influences, assumed to be proportional to the size of the pool of Potentials (P); and the rate based on word of mouth and the implied positive feedbacks that the Adopters (A) transmit to the Potentials, and so assumed to be proportional to PA. The contribution from word of mouth is assumed to be independent of the contribution from advertising and other external sources.

35. Bass (1969/2004), p. 1826

36. The book Bass refers to as Rogers 1962 is listed in the references to Bass (1969/2004) as Rogers, E. M. *Diffusion of Innovations.* The Free Press, New York. 1962

37. Sterman (2000), p. 332

Figure 7. The Bass diffusion model[a]



a. Adapted from Sterman (2000) p. 333

Based on the systems-thinking structure postulated in figure 7, the systems-dynamics model defines the probability that a potential adopter will adopt the innovation as a result of the advertising and external influences as a constant, a. So the contribution of advertising to new adopters is defined to be aP per unit time. This model further assumes that people in the relevant population (both P and A) come into contact at a constant rate of contact, c per person per unit time. Thus the total rate of contact generated within the Potential pool is cP. Of those contacts, the fraction A/N is the probability that any contact is with an Adopter who may transmit information about the innovation. Finally, the probability that such a contact results in adoption is also assumed to be constant, symbolized by i.

Based on these assumptions, the systems-dynamics model becomes

$$AR = aP + ciPA/N$$

When A = 0, that is, when the Adopter base is 0 at the inception of the innovation, only advertising and other external sources can trigger adoption. Once the population of early adopters begins to grow, however, the feedback loop based on word of mouth will come to dominate the growth of the Adopter population, decreasing the effect of advertising as the pool of Potentials grows progressively smaller.

This example illustrates how a qualitative causal loop diagram (a systems-thinking model) can help analysts construct quantitative (systems-dynamics) models to explore issues amenable to mathematical analysis. For the gamer, both the qualitative and the quantitative models are potentially useful. For wargames, in particular, quantitative measures frequently play a major part in characterizing the effects of player decisions. Poorly conceptualized or non-representative quantitative models, which produce quantitative outcomes difficult to reconcile with player expectations or experience, can drive a wargame to rapid and irreversible disaster. Poorly conceptualized or incomplete qualitative models can drive the players to consider issues and effects whose influence in the real world is marginal or only poorly understood.

Both the qualitative contributions of systems thinking and the quantitative contributions of systems dynamics are of potential value to wargame designers. Because our primary interest in the current study lies in the realm of systems thinking rather than systems dynamics, our next example investigates how systems-thinking formalisms can help the analyst and wargamer structure a complex real-world situation in practically useful ways, even using only a qualitative causal-loop approach.

A systems-thinking example: theater security cooperation

As part of an exploratory effort to apply systems thinking to operational and strategic issues in the area of responsibility of the Commander, U.S. Naval Forces Central Command (COMUSNAVCENT), Naval War College Professor Stephen Downes-Martin developed a set of causal-loop models to represent different aspects of the political-military environment in the region.[38] One of these models represented the dynamics involved in creating a

38. Downes-Martin (2008)

program for theater security cooperation (TSC), focused on counterterrorism (CT), among the United States and the regional nations (RN) and their maritime forces (RNMF). In the discussion that follows, there is an assumption that the principal target of CT operations is the loose confederation of terror organizations known as Al Qaeda and Associated Movements, or AQAM.

The actual approach taken to building this model followed a series of phases. As described by Professor Downes-Martin, these phases track quite well with corresponding steps frequently followed during wargame design and execution. Table 1 shows the comparison.

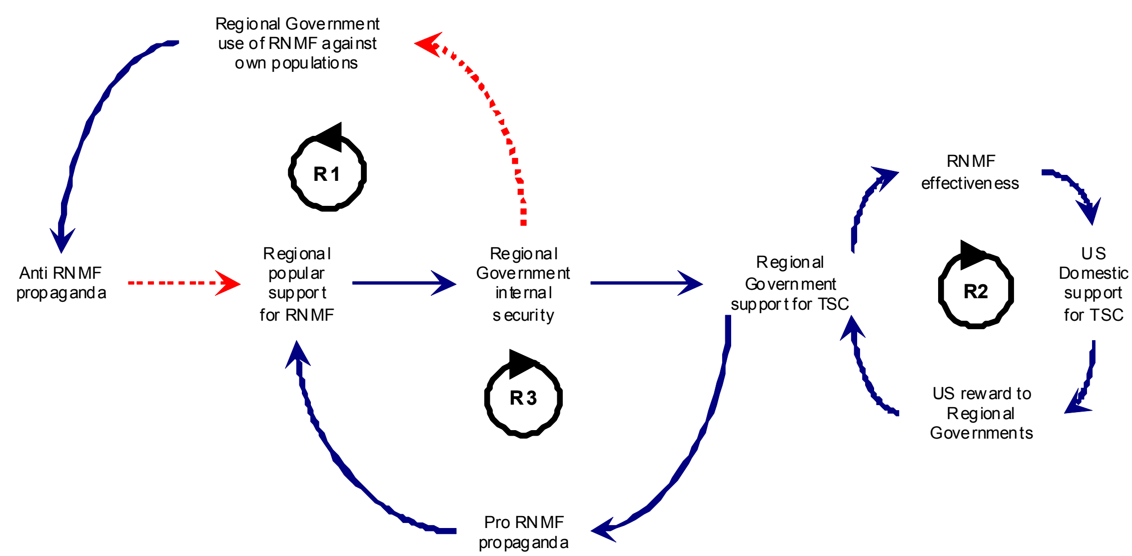
Table 1. Systems-thinking model and game development processes

Steps in ST Model Development	Steps in Pol-Mil Game Development
1. Elicit sponsor objectives	1. Elicit game objectives
2. Identify important perspectives	2. Prioritize and bound (or limit) game topics
3. Engage Subject Matter Experts (SMEs) and drill down on each perspective with the relevant SMEs	3. Conduct in-depth research on topics to be represented in the game
4. Build cause-and-effect loops and integrate them	4. Identify scenario interactions of interest
5. Explore the effects of actions on the model	5. Adjudicate player actions during the game

Both development tasks begin with eliciting a clear and understandable set of objectives from the sponsor of the effort. The scope of the effort is defined based on those objectives. In the case of the systems-thinking model, the process the Naval War College used was to involve subject matter experts by asking them to define the key perspectives the model would incorporate. Once the set of perspectives was defined, the researchers would probe the details of each perspective with the various SMEs. This process of research is analogous to that used in wargame design to scope and research the topics to be included in the game. With the perspectives defined and researched, the systems modeler constructs the causal-loop diagrams to capture the key relationships; the wargame designer's process incorporates the results of the research into defining the key interactions the game strives to have the players explore. Finally, both techniques must turn the key and run the model, either to explore the interactions of the causal loops or adjudicate the interactions of the players.

To show the detailed thinking that went into building even this relatively simple model, Professor Downes-Martin has allowed us to use both the graphics and text from his unpublished explanatory briefing. We have made only minor modifications to what follows.

Figure 8. Regional government cause and effect diagram[a]



a. RNMF: Regional Nation Maritime Force; TSC: Theater Security Cooperation; AQAM: Al Qaeda and Associated Movements

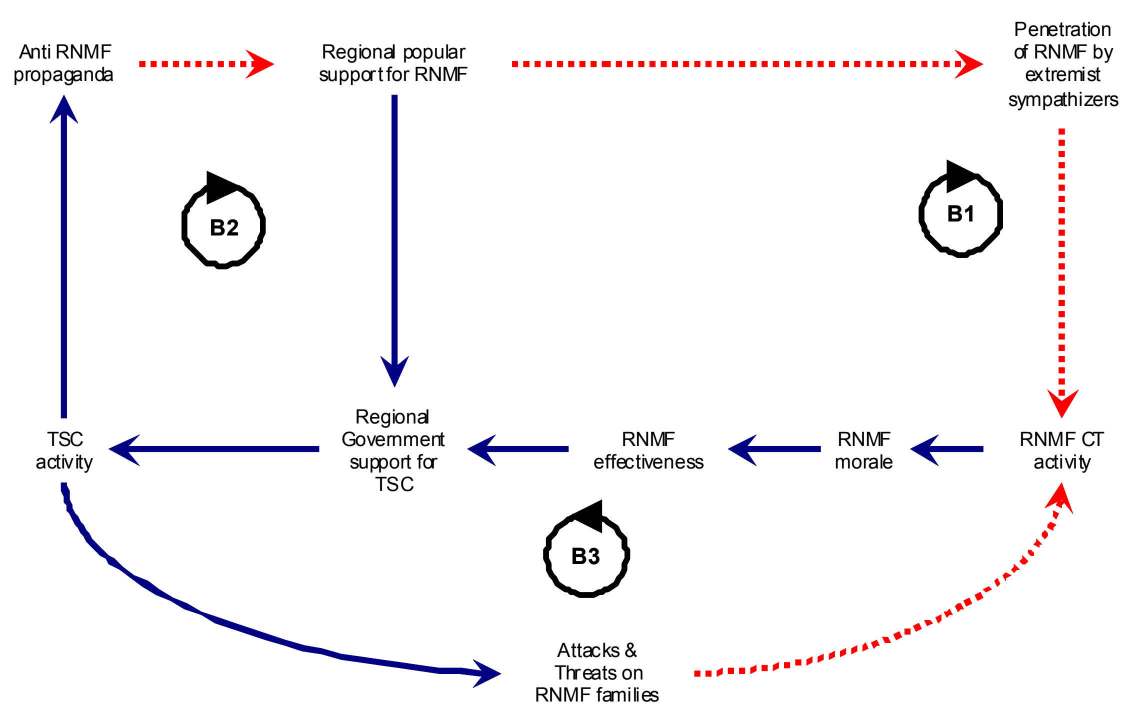
Figure 8 shows a causal loop diagram relating the cooperation of a Regional Government and its maritime forces with the United States to the internal political position of that government. The model posits three reinforcing loops linking the nine elements involved in this perspective.

- Reinforcing Loop R1: “RNMF Targets regional populations.” Regional governments will be tempted to use effective RNMFs against regional populations in support of what they see as regime security problems. This will provide propaganda opportunities for the AQAM which will drive down popular support for the RNMF and place regime security at risk. With regime security at risk due to RNMF activities, the regional government's support for TSC activities will diminish.

- Reinforcing Loop R2: "Reward Regional Governments for engaging in TSC." Regional government support for TSC will drive up RNMF effectiveness which will be perceived by U.S./ Coalition domestic politics as beneficial to the Counterterrorism (CT) cause and thus result in domestic political support for TSC within the United States and other Coalition partners. This political support makes it easier to provide diplomatic and economic rewards to regional governments to assist in overcoming the internal and extremist threats to their regime's security created by cooperating with the Coalition.
- Reinforcing Loop R3: "Effective pro-RNMF propaganda." Regional government support for TSC will result in effective propaganda aimed at building regional popular support for RNMF and for TSC activities.

Figure 9 shows the second major element of the model, the relationships among government and AQAM action and their effects on the popular support for regional governments. This aspect of the model relates nine elements using three balancing loops.

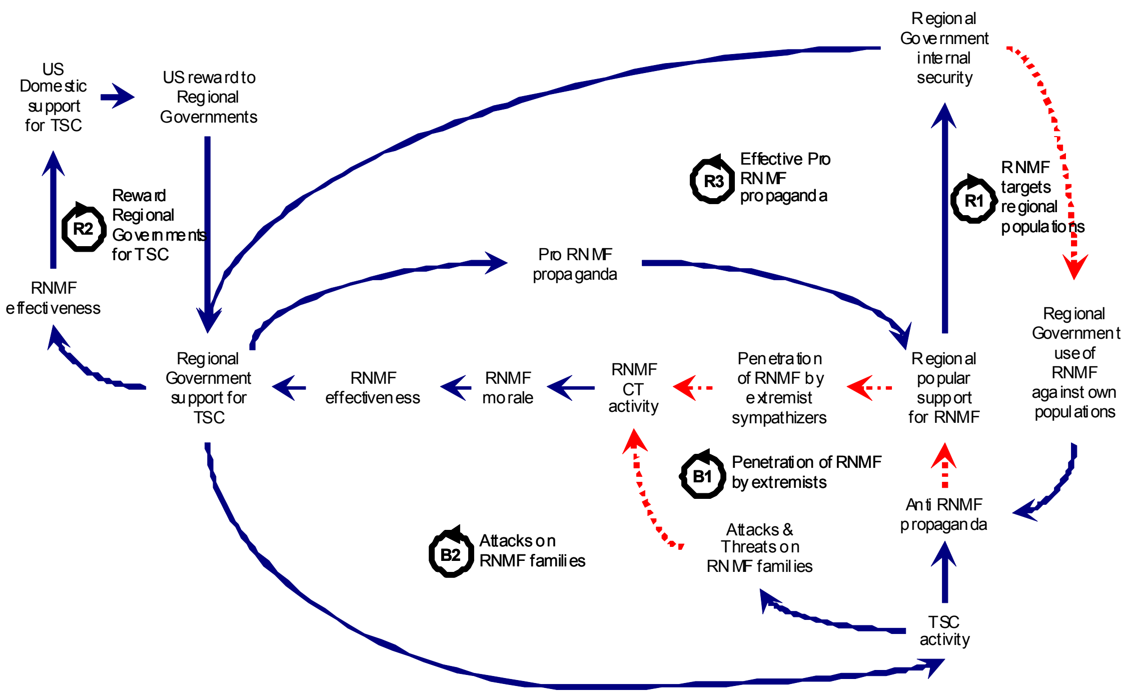
Figure 9. Regional public cause and effect diagram



- Balancing Loop B1: "Penetration of RNMF by extremists." AQAM react to TSC activities with propaganda designed to drive down the regional popular support for the RNMF and increase recruitment of RNMF personnel to extremist ideological views. This results in a drop of CT activity by the RNMF and a drop in RNMF morale, and hence a drop in RNMF CT effectiveness and a drop in Regional government support for CT ops as the benefits of TSC activities are outweighed by the downsides. The government then becomes unenthusiastic for TSC.
- Balancing Loop B2: "Regional popular support for RNMF." Regional governments are sensitive to popular feeling even though they are not democracies.
- Balancing Loop B3: "Attacks on RNMF families." AQAM react to TSC activities with threats and acts of violence against RNMF families, thus driving down RNMF CT activity and driving down RNMF morale. A drop in RNMF CT effectiveness thus occurs followed by a drop in Regional government support for CT ops as the benefits of TSC activities are outweighed by the downsides. The government then becomes unenthusiastic for TSC.

Finally, combining the results of both sub-pieces, figure 10 shows the integrated model.

Figure 10. TSC integrated cause and effect diagram



- Balancing Loop B1: "Penetration of RNMF by extremists." AQAM react to TSC activities with propaganda designed to drive down the regional popular support for the RNMF and increase recruitment of RNMF personnel to extremist ideological views. This results in a drop of CT activity by the RNMF and a drop in RNMF morale, and hence a drop in RNMF CT effectiveness and a drop in Regional government's support for CT ops as the benefits of TSC activities are outweighed by the downsides. The government then becomes unenthusiastic for TSC.
- Balancing Loop B2: "Attacks on RNMF families." AQAM react to TSC activities with threats and acts of violence against RNMF families, thus driving down RNMF CT activity and driving down RNMF morale. A drop in RNMF CT effectiveness thus occurs followed by a drop in Regional government support for CT ops as the benefits of TSC activities are outweighed by the downsides. The government then becomes unenthusiastic for TSC.

- Reinforcing Loop R1: "RNMF Targets regional populations." Regional governments will be tempted to use effective RNMFs against regional populations in support of what they see as regime security problems. This will provide propaganda opportunities for the AQAM which will drive down popular support for the RNMF and place the regime's security at risk. With regime security at risk due to RNMF activities, the regional government's support for TSC activities will diminish.

- Reinforcing Loop R2: "Reward Regional Governments for engaging in TSC." Regional government support for TSC will drive up RNMF effectiveness which will be perceived by U.S./ Coalition domestic politics as beneficial and thus result in domestic political support for TSC within the United States and other Coalition partners. This political support makes it easier to provide diplomatic and economic rewards to regional governments to assist in overcoming the internal and extremist threats to their regime security created by cooperating with the Coalition.

- Reinforcing Loop R3: "Effective pro-RNMF propaganda." Regional government support for TSC will result in effective propaganda aimed at building regional popular support for RNMF and for TSC activities.

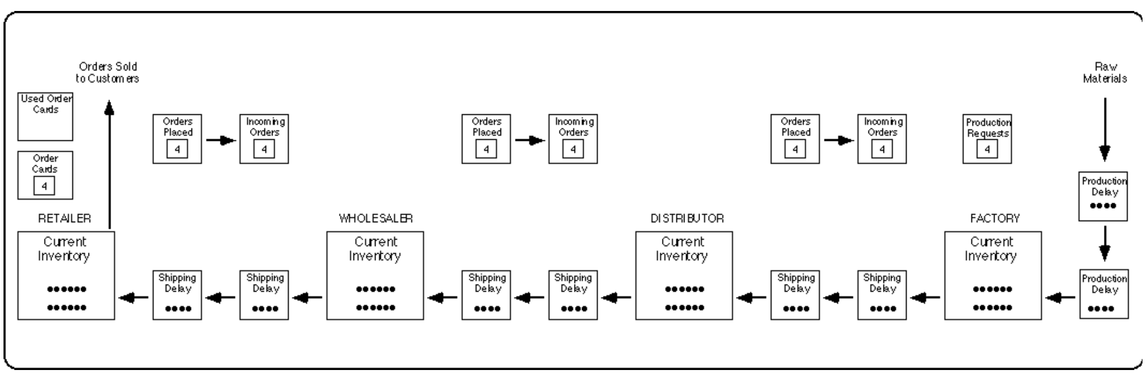
This TSC model is only a small part of a larger effort to create cause-and-effect models to assist COMUSNAVCENT in thinking about their complex responsibilities in dealing with regional nations and coalition partners. The form and details of the models created by the Naval War College were driven by the "overarching goal" of the TSC program, that is, "to persuade U.S. and Coalition partners to continue supporting the mission with platforms by providing evidence that the Coalition is achieving its objectives, and that such success is dependent on Coalition partner support." The resulting model and analysis thus focused on the kinds of political pressures that stem from either success or failure to achieve those objectives. Does the model capture most of the key elements associated with these issues in the real world?

Answering that question is a task for subject-matter experts (SMEs) whose in-depth expertise would contribute to refining and testing the model. One way of conducting such testing is to design a game to explore the reactions of experts when placed in a dynamic simulation of the real environment. The power of gaming based on such systems thinking models is illustrated by our final example.

The Beer Game

We will conclude our tour of examples of systems models with one of the most popular and widespread of all, and a game to boot. As we mentioned earlier, the Beer Game was created in the 1960s by MIT's Sloan School of management and contributed to Forrester's early research.[39] Figure 11 shows the game board for the Beer Game, which depicts the production-distribution chain of “beer” for purposes of game play.

Figure 11. Game board and production/distribution system for the Beer Game



As Sterman describes the game, it represents the supply chain in a typical manufacturing industry. The supply chain has four sectors: a retailer, wholesaler, distributor, and factory. Each stage is identical and managed by a different person. The managers strive to minimize

39. See Sterman (1992) for a brief overview of the game and some of its outcomes

their costs by controlling inventories as they seek to meet incoming demand. The simulation shows the response of the factory order rate to a one-time change in customer orders.[40]

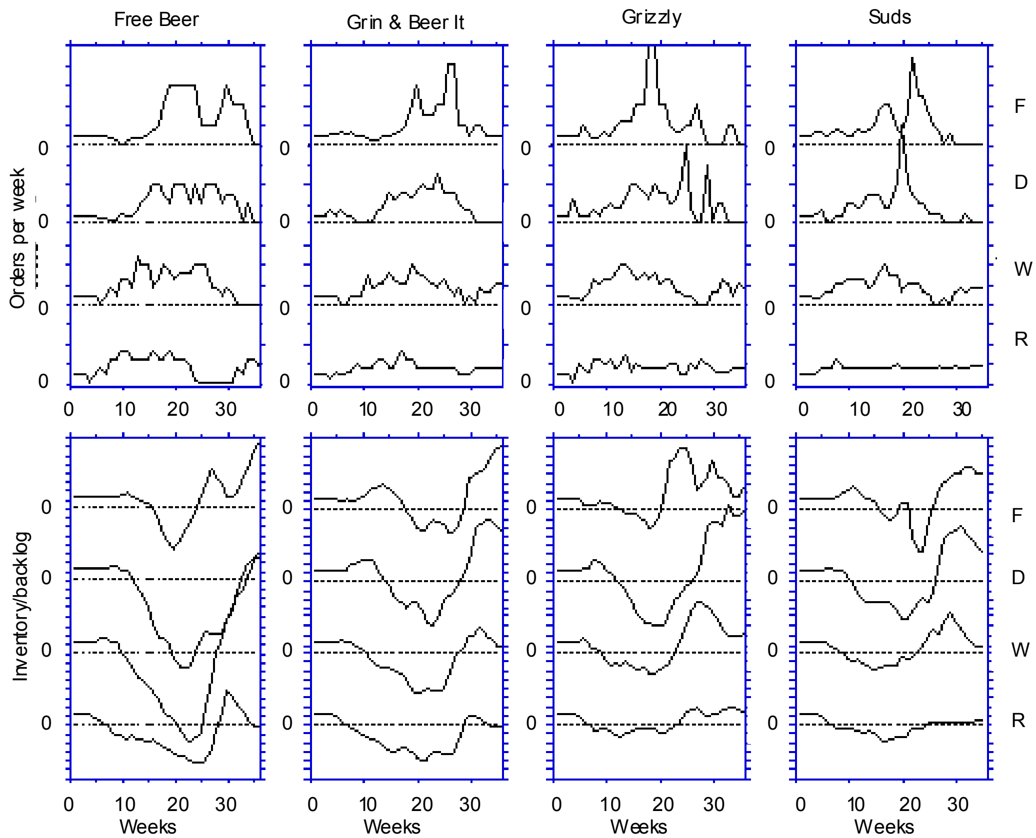
Orders for additional product flow across the top of the figure, while actual product flows—through the arrows—across the bottom. There are shipping delays and production delays, represented by the sequence of boxes through which the product must flow. Each player must pay a cost for maintaining inventory and a penalty cost for backlog fees when they cannot meet the demand of their customer. The players communicate with each other only through the orders they place, and only the retailer gets to see the actual customer demand. The objective of the players is to minimize their total cost (that is, the costs of the entire chain).

In its classical form, the game begins with a constant customer demand of four cases of beer from the retailer for each game turn of play. The supply chain itself is fully stocked and players each have orders in place for four units from their supplier. The players are told to order four cases each for the first three turns of the game, after which they are free to order what they wish. They are also told that customer demand may change over time. In fact, however, there is only one such change, which doubles demand from four to eight units at turn five. That demand stays constant for the rest of the game. Amazingly, perhaps, this simple one-time shift produces complex dynamics within the simple supply chain when players have such severe limitations on the information they can share. As an example, here is what Sterman has to show—and say—about the sorts of results he observed.[41]

40. Sterman (2000), p. 130

41. The figure and the extended discussion are from Sterman (1992)

Figure 12. Sample results from the Beer Game



Each column shows the results of a single team. The top four graphs show the orders placed by the players, from the retailer (bottom) to factory (top). The bottom four graphs show the players' inventories and backlogs (negative values), in the same order. Average team costs are about $2000, though it is not uncommon for costs to exceed $10,000; few ever go below $1000. Optimal performance (calculated using only the information actually available to players themselves) is about $200. Average costs are ten times greater than optimal!

More revealing, the departures from optimality are not random. Though individual games differ quantitatively, they always exhibit the same patterns of behavior:

> 1. Oscillation: Orders and inventories are dominated by large amplitude fluctuations, with an average period of about 20 weeks.
>
> 2. Amplification: The amplitude and variance of orders increases steadily from customer to retailer to factory. The peak order rate at the factory is on average more than double the peak order rate at retail.
>
> 3. Phase lag: The order rate tends to peak later as one moves from the retailer to the factory.

In virtually all cases, the inventory levels of the retailer decline, followed in sequence by a decline in the inventory of the wholesaler, distributor, and factory. As inventory falls, players tend to increase their orders. Players soon run out of stock. Backlogs of unfilled orders grow. Faced with rising orders and large backlogs, players dramatically boost the orders they place with their supplier. Eventually, the factory brews and ships this huge quantity of beer, and inventory levels surge. In many cases one can observe a second cycle.

There are many lessons that might be drawn from the play history of the Beer game. Indeed, Sterman (1992) and (2000) discuss many of those lessons in detail. For our purposes, however, the key ideas we would like you to take away from this example are only two:

- People playing games will sometimes misread their situation and make decisions that seem reasonable at the time but prove less than optimal (or even intelligent) when studied outside the hot house atmosphere of the game itself.
- Indirect communication between actors—that is, communication based only on actions rather than an exchange of pertinent information about why they are taking their actions—usually leads to misunderstandings, misinterpretations, and poor play, whether in a game or in real life.

Game designers forget or ignore these lessons at their—and their players'—peril.

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Relating ST models to games, and games to ST models

In the second half of this paper, we expand our discussion to consider systems thinking (ST) from two new perspectives: how ST can be used to enhance game design and execution, and how games can be used to create inputs to, or test, ST models. This first section takes an overview of the subject. The two major sections that follow will address the discussion in more detail from the two perspectives. First we focus on applying ST models to games—including how designers, control and players can interact with ST models during the course of game design and execution. In the second section we focus on applying games to ST models.

This section establishes a framework for that extended discussion. It is important within this framework to understand how ST models may integrate into a game design, and to identify which aspects of ST models make them most applicable to gaming. At a basic level, ST models can either address processes that are "internal" to the overall game design (helping players organize, providing control information about organizational relationships) or "external" to it (representing the threat or other non-player entities). This section also discusses what makes ST models special and which elements of those models are most relevant to games.

Internal and external processes

What do we mean by processes "internal" and "external" to a game?

- Internal processes are bureaucratic and organizational structures or roles that the players might typically interact with in a game.
- External processes are those that make up the environment and opposition.

External factors set the context within which the players act; internal factors set up the organization and constraints within which the players act.

In our example of a game dealing with the political-military situation in the Pacific, the internal processes include the decision and command organization of the Pacific Command, or possibly the Pacific Fleet, depending on the principal consumer for the game. Because the players would be playing some or all of the roles in the command organizations, the players would be "embedded" within these internal processes. Game designers would want to understand how the real processes work, in order to better situate the players in the game.

External processes include any friendly, allied, or hostile countries—especially countries opposed to U.S. interests—in order to capture the overall environment within which the Pacific commands have to operate. These external processes could be represented in the game by computer models, by the control cell, by subject-matter experts supporting control, or by actual players taking on some of the roles that represent these external processes. Game designers would need models that simulate the environment, or they would need to understand relationships between the various organizational and political entities in order to better place experts or threat players within the game.

ST models can operate across the spectrum of internal and external game processes. As we will discuss in the following sections, ST models can function like traditional models or simulations and represent entire processes within the game (e.g., the threat) or they can serve as examples of how processes and decision loops within the organization can be simulated by the players in the game.

How do ST models relate to games?

Defining a mutually supporting relationship between games and ST models can begin by considering whether the relationship resides primarily in the design of the game, or in the execution of the game design—that is, during the play of the game. ST models can play a role in both cases, supporting the designers by giving them insights into the problem they are working on, or by providing players or controller's information and insight about the workings of the world or environment they are dealing with in the game.

In the following sections we consider each of these alternatives, both for ST models supporting games, and for games supporting ST models.

What makes ST models special?

Models are used all the time in games, and are key components of many computer games. So in order for this discussion to be relevant to ST models and games, it will be important to explore what is different about ST models and other types of models.

For the purposes of game design, the key difference between ST models and other types of models lies in the underlying similarity of the process of building ST models to the process of designing games. The collection of data, the identification of relationships and feedback loops, and the emphasis on human interaction all are key components of both ST models and games. Most "traditional" models simulate some aspect of the physical world, whether it is the movement of objects or the resolution of combat. Fewer models simulate human decision-making, and when they do, they often seek to replicate individual internal decision processes rather than the social networks that affect decision-making. ST models directly address the underlying relationships and linkages inherent in organizations; once again, this means that they are similar in construction and intent to games.

Because of this affinity, we begin by discussing exactly how ST models relate to games, drawing from our previous discussion of Forrester's work. In the remainder of this section we will use this similarity as the basis for our discussion about how ST models may be used to construct as well as execute games.

Key elements of ST models for game purposes

Forrester distinguishes his view of systems thinking and systems dynamics from other approaches along two principal dimensions: endogenous variables and sources of information. In particular, he argues that in systems dynamics, "the model boundary is to be established so that the causal mechanisms lie inside the boundary." Games take note! "People are far more comfortable blaming their troubles on uncontrollable external causes rather than looking to their own policies as the central cause."[42]

Allowing a game to become dominated by a *deus ex machina* is most dangerous precisely because it gives the players an "out"; their fate must be clearly related to their own decisions, not to the whims, vagaries, and manipulations of "Control." Just as "Systems dynamics models build from the inside to determine and to modify the processes that cause desirable and undesirable behavior,"[43] games create the conditions that trigger player decisions and show them the effects of those decisions on the game environment.

Forrester also argues that systems thinking models use a far wider range of information about its target system than many other academic approaches, particularly those of the social sciences. He distinguishes three sources of data, each within an increasingly narrow scope and value: the mental database (a key element of systems thinking modeling), the written database, and the numerical data base (the smallest, and yet the source most heavily relied upon by many social scientists as somehow more "real" than the others).

What's more important for his purpose of constructing a systems thinking model, the critical information about the structure and policies decreases dramatically as you move from the mental to the numerical data bases. "The mental data base is especially concerned with policy, that is, why people respond as they do, what each decision-making center is trying to accomplish, what are the perceived penalties and rewards, and where self-interest clashes with institutional objectives."[44]

42. Forrester (1991), p. 22

43. Forrester (1991), p. 23

44. Forrester (1991), p. 24

He sees the component of the written data that deals with "the present" (rather than historical or "professional" accounts) as most useful for modeling purposes because, as he puts it, "Policies govern decisions and decisions control action. Decisions are fleeting. There is only a single instant in time when one can act. That time is now. Action must take place in the present moment that separates history from the future."[45]

Numerical data seldom provide either "direct evidence of the structure and policies that created the data … [or] the cause and effect directions among variables."[46] On the other hand, numerical data can provide values for important parameters, summarize important long-term characteristics of systems (such as the average periodicity of business cycles), and collect the time-series information useful to compare model output to reality—if not necessarily to help calculate the parameters of the model.

Most important, the integration of useful information from all three sources is the key to designing an effective systems dynamics model. Indeed, all information is admissible to the process of model building. Information from the mental database is recognized as a rich source of knowledge about structure and the policies governing decisions. Parameter values are drawn from all available sources, not merely from statistical analyses of time series. The mental and written data bases are the only sources of information about limiting conditions that have not occurred in practice but which are important in determining the nonlinear relationships that govern even normal behavior.[47]

All of the important characteristics of systems thinking models described in this section apply almost word for word and idea for idea to the building of wargames dealing with reality. A game is inherently a dynamic system model in which the players make decisions based on their pre-existing mental models, drawing on their internal experiences and understanding as well as both written and numerical data bases. The link between wargaming and systems thinking is both clear and strong.

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45. Forrester (1991), pp. 24 – 25

46. Forrester (1991), p. 25

47. Forrester (1991), p. 25

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Using ST models to support games

In order to grapple further with the question of how ST models can best support wargaming, we need to examine the role that models of any type play in games.

Models, simulations, and games are closely related, but distinct, activities. Because we are mainly interested in games here, we can say that games may—but are not required to—employ models in various ways in order to represent or replicate the behavior of the world the game is trying to present to the players. Whether or not a computer model is used, any game about a serious subject will require a design, and will also require that the design present an accurate reflection of the real world to the players. At a minimum, the model has to be sufficiently accurate that the players do not rebel against it out of disbelief in the game's representation of reality.

Thus in their simple role as something that mimics the world, ST models can be integrated easily into games in the way that any other model would be used. Because the typical use for a model in a game is to support or assess the decisions made by either the players or control, then an ST model that provides output appropriate to game play could be used by control to aid it in evaluating the decisions and actions of the players in the game. For example, if a game focused on U.S. engagement activities designed to encourage countries in the Pacific region to behave a certain way, then possible player actions could be defined just as easily as inputs to an ST model of the region; that model could then be used to evaluate what the effects of such actions might be on the attitudes of the target countries.

The model could either produce a generalized ST positive or negative output, or it could be expanded into a full-scale systems dynamics model with detailed, numerical, inputs and outputs. This would depend greatly on what was being modeled, with the more obviously quantitative subjects (economics) lending themselves more readily to systems dynamics treatment than the more obviously qualitative ones (politics).

But the support that ST models can provide to wargaming goes beyond the simple application of such models during games. In any but the simplest games the goal is to examine not only player decision-making processes, but also the dynamic relationships between the various decisions players make. Understanding the dynamics of an interacting system can lead to the discovery of things that would not otherwise be revealed by a linear, prosaic, investigation of the topic. These "perversions" of the expected, which arise in games more frequently than in other forums, stem from several different roots:

- Unspoken (or unspeakable) predispositions and goals held by individual players or groups. For example, while organizationally it may be preferable for one group to sacrifice funding or influence so that the overall organizational goals may be achieved, that group may in fact deliberately or inadvertently sabotage the overall organizational goals by pursuing their own interests. Because games are often perceived as "fictional," they can bring out such latent self-interested tendencies in players, and demonstrate their perverse effect on the organization's goals.

- Feed forward (domino) effects, in which the action of one individual or group influences another, which then affects a third, and so on, until groups or activities that are remote from the first action experience effects they otherwise would not.

- Feedback loops, in which an action of one individual or group affects the behavior of other game elements, such as the enemy or opposition, whose subsequent actions eventually come back and affect the original player. At their most basic level, these feedback loops help the players see the results of their actions. But of course many players taking many different kinds of actions can generate many simultaneous feedback and feed-forward effects that end up interacting with each other in complex and unpredictable ways.

Games are uniquely capable of bringing out these effects, even when the designers and players did not know they existed. It is the job of the game designers to identify and set up the players with situations in which predispositions, effects, and feedback loops can spontaneously come about through the course of the game. They can do so by carefully crafting the story of a game to bring out these effects, or by identifying key player decisions that will produce the greatest number of challenges.

Dealing with these various feed-forward and feedback loops, along with unspoken or unanticipated player actions, is where ST models can provide unique support to the design phase of the game.

ST model support for the game-design phase

How can ST models support the game design process? In general, there are two ways that models and simulations can be used to support game design: they can allow game designers to understand better the processes and issues they are dealing with, and they can provide game designers with ready-made modules to implement some elements of the game's design or mechanics. If you can employ a pre-existing model to implement a major part of the game, then you have less work to do as a designer.

Typically when models are used to implement a part of the game, they are used either to resolve player actions, or to represent the actions of non-player elements in the game, such as the opposition. In addition most games have some form of “mechanics,” which direct how players interact with each other and the flow of the game, and also form a system by which player actions are resolved. A much less common way to integrate models into games is by using the models to suggest game mechanics and flow. Systems thinking models may inspire this more frequently than conventional models, due to their similarity to the underlying intellectual processes of games.

For example, in our hypothetical game dealing with the Pacific region, the game designers may have at their disposal a model of intelligence, surveillance, and reconnaissance (ISR) systems, which predicts what intelligence is available from various overhead and air-breathing systems. They might also have available a ground-combat simulator, which, if given the terrain and forces involved, would produce an approximate outcome of a large-scale ground engagement or battle. Although both of these sub-systems are important devices the controllers can use to adjudicate results in the game—and using them will mean that the controllers are relieved from a large amount of work trying to figure out how otherwise to simulate those processes—the models themselves are not really important in the overall problem of designing a game about the political situation in the Pacific. In fact, designers risk missing the central point of the game if they try too hard to accommodate such simulations in their design; they could easily focus on the wrong problems and miss important relationships that do not involve intelligence or combat.[48]

One unique aspect of ST models is that they attempt to characterize or simulate the PMESII processes that typically are not simulated by more mechanical military or other simulations. For example, in our notional Pacific game, ST models might simulate the relationships between third-party countries not represented in the game by either experts or control. The ST models would provide control a way to determine the actions of those countries, substituting for an important element of the game, which designers would otherwise have to figure out how to represent using other techniques.

Because ST models deal with the human and political aspects of processes, they also may be able to help the designers during the design portion of the process itself. This makes ST models more broadly applicable in game design than other models.

An ST model that covered the entire subject area of the design—the entire Pacific region in our example—would give designers a leg up on understanding and identifying key relationships between countries in the region. For example, suppose Chinese military expansion were linked to political behaviors amongst large segments of the

48. The focus on such distractions often occurs in game designs when the game's sponsor (or game director) has particular issues or systems that they want to incorporate into the design, whether or not the systems or issues in question actually address the game's objectives. Typically, this situation will result in negotiations between the designers and sponsors in order to address effectively all of the sponsor's principal objectives while avoiding distracting side issues.

Korean and Japanese populations. Such action might, in turn, create more animosity toward China in those countries, which then resulted in even more of a military buildup in China (a feedback loop). Based on this ST analysis, game designers would better be able to see and understand that relationship and so design the game's scenarios and mechanics to shape players toward making more realistic decisions about the related issues.

Although any model or simulation can be plugged into the game to represent specific processes or systems, game designers need to understand the entire system that the game addresses, and seldom benefit from delving into too much detail on specific sub-systems and processes. A primary consideration for designers is understanding how the players will work with each other and interact, especially when that interaction is a contentious one. Should the game be conducted in a series of moves or should player actions proceed simultaneously? How will players acquire information about the decisions and actions of other players? How will they communicate? Typically designers answer all of these questions based on their understanding of how real-world limitations and capabilities affect the key issues that the game is designed to address. If communications can lead to important misunderstandings among the players, then reflecting a realistic communications style in the game will be important. ST models, unlike the combat or ISR models described earlier, can provide designers insight into relationships and linkages between players and organizations represented in the game. This “model” for how things work may provide a partial foundation for the design of the game's basic mechanics.

Thus classic warfare models, while they can be used to implement certain large pieces of a game, do not usually help the designers when they are attempting to envision and design the overall game. ST models may be an exception to this; by depicting the interwoven network of relationships and interactions among complex elements of the environment, they may be able to provide the designers a basis for structuring key elements of the game design and the game mechanics.

The similarity between ST models and games—with their emphasis on political interrelationships, unintended consequences, domino effects and feedback loops—make ST models a research tool for encoding information that would be of direct use to game designers. In order to develop the ST models, the model developers have to go through many of the same processes that game designers do—understanding the issues and objectives, collecting information, and coding relationships into a tangible form of expressions. ST models can provide designers a "book" of relationships and causal effects that they could then "read" (whether by running the model or by taking it apart) in order to understand better the problem they were tasked with designing a game to address.

It is important to note, however, that ST models will only be as good as the information and insight available to those who design them, just as is the case for games. Thus game designers will need to assess and evaluate the ST models to determine how much useful information they contain, and how much additional information and design thought will be needed beyond what is in the ST models. Of course, this works both ways; ST models can provide experienced game designers a useful technique for encoding their insights into a problem in a way that future designers could pick up and use when designing a game on similar subject matter.

In using ST models for the design phase a couple of cautions and caveats come to mind:

- The knowledge encoded in an ST model represents the model developer's understanding of the process based on current (perhaps expert) inputs. These inputs are likely to change over time, either making the model less useful as time goes along, or requiring constant updating of model relationships and coding.
- ST models are based on information and expertise about the issue they cover. This means that unusual or unanticipated relationships may not be covered in the model, either because they are too improbable or simply not considered by the experts. An example in our Pacific game might be the development of an alliance between Japan and China. Game designers need to

understand the potential for such an alliance, and its potential effects, and bring to bear their own judgment on how to address the issue. Unlike the political expert, the game designer's judgment is more likely to see the need to identify and incorporate such improbable or unexpected events into the possibilities inherent in the game.

The discussion above leads us to the following summary observations:

- Small-scale ST models that address part of the overall game problem may function like any other model in being able to implement subsystems in a game's design. This means designers will have to do less work (assuming they do not design the ST model themselves). Furthermore, the fact that ST models simulate political relationships may make their contribution unique among the "usual suspects" of DoD models.
- ST models can help game designers gain insights into relationships, feed-forward processes, or feedback loops that they may wish to incorporate into the overall design.
- Large-scale ST models may be used to assist the game designers, but should seldom be incorporated directly into the game design. Simply using them as the core of the game's design would mean that the resulting analysis and insights would really derive more from the model, not from the game itself.

ST model support for the game-execution phase

In addition to support for the game-design phase, ST models may also play a role in the execution phase of a game. Our previous discussion of how ST models might support game designers focused on internal issues such as player interactions or how and what information might be presented to the players; in this section we are almost solely concerned with external issues, such as how ST models might represent entities or organizations not represented among the game players.

It is important to note that, for the same reason that ST models might be useful to the design process, however, they might provide more limited support to the game-execution process. If an ST model of potential use covers a piece of the overall game problem, then it simply could be “dropped in” and used by control to adjudicate results. (For example in our Pacific game you might consider employing an ST model of North Korea.) However, if the model describes the workings of the entire region, then dropping it in would mean that the model would have a significant effect on the overall design of the game, perhaps even substituting for that design. This might not be advisable, because the goal of the game should be to examine the decision making processes of the players, and such an ST model might severely constrain or limit those processes. Likewise the model would not necessarily incorporate the role of decision making into its description of the system, and thus miss the key element of gaming.

This caveat, that ST models might become too big a part of the overall game, is important to keep in mind in the following sections as we discuss support by ST models to controllers, principal players, and the opposition or threat, which can involve both such groups.

Support to controllers

ST models can provide support to a game's controllers in several ways:

- Representing the threat directly. If threat players are not actively involved in the game, then ST models could represent how player actions will positively or negatively affect various threat decisions. For example, in our Pacific game, an ST model of North Korean decision making might be used to represent the North Korean leadership. This model would represent how U.S. player actions as well as internal developments might affect whether the North Koreans would become more or less aggressive.

- Representing organizations not actually involved in game play. One of the most significant deficiencies in many military games is the lack of realistic interagency and political play. Political and interagency considerations often have a substantial effect on which course of action senior political decision makers will choose, and what limits they will impose on the military players. An ST model of the U.S. political or interagency processes would enable controllers to incorporate such actions in the game without requiring large numbers of political players, or simple assumptions about behavior. Also, because the ST model could be vetted and described to the players, their skepticism about the outcomes would be less than if control imposed those outcomes through some other less open game mechanic.

- Adjudicating player actions. Although this is a subset of "simulating organizations not in play" it is a significant subset given joint and Navy interests. Because much of what goes on during peacetime or low intensity operations (such as the GWOT) involves influence or engagement operations, it can become important to design games that address influence operations. Adjudicating whether a country or entity in the game has been influenced by player actions can be a problem, both because the knowledge needed to do it in a strictly objective way does not exist (even if such a thing were possible), and any adjudication by control or an expert can be challenged as subjective. Because ST models may be designed specifically to address PMESII issues, they have both the capability to address adjudication of engagement problems, and be examined by decision-makers (or their representatives) and agreed upon as an "objective" means of adjudicating such actions.

Because most models could provide adjudication support of some type to controllers, the real question is how ST models might be unique in their capability to provide such support. The key characteristic of ST models is that they deal explicitly with human and social relationships, relationships that are key for understanding PMESII elements. ST models also provide indicators of positive or negative influence, as opposed to specific results. Most combat—and other—traditional models try to generate specific or quantitative results as much as possible. The shortage of widely agreed upon quantitative measures for PMESII inputs is an advantage; it allows controllers to base their decisions on model "results," but also to adjust or interpret those results in a way that will more effectively facilitate game play.

These two attributes of ST models, the ability to represent complex relationships and the generalized output from the models, both distinguish them from more traditional quantitative models.

Support to players

In the same way that controllers could use models to adjudicate game results or represent what organizations not playing in the game might do, the players of a game could also use ST models as play aids during the game. Often in games players are called on to make judgments about how their actions will affect the game world. While most military players understand weapons systems and operational effects, they are often less prepared to assess how their actions will affect political, economic, or informational aspects of a conflict. Typically they would rely on advisors, such as political advisors, but such experts may not always be available in a game.

Because ST models of PMESII can give an insight into how subject matter experts might believe an action will influence various groups and organizations in a region, players can use the models to help them understand better how their actions will be received, before they take them.

The biggest challenge to implementing ST models in support of player decision-making stems from how such player aids relate to the processes and tools controllers use to adjudicate the actions of those players. Simply using the same ST model to adjudicate the results will produce the unhelpful case of the "model playing the model." This will give players too much information about the effects of their actions, and thus the future. Any modification to the model results, however, will then result either in the players charging that the adjudicators do not know what they are doing (if the adjudication is done by live persons), or in the players disbelieving the effectiveness of the model and its results.

In order to avoid creating either a self-fulfilling prophecy or disgruntled players, it may be necessary to carefully construct how the model and its results are presented to the players. For example, the model might avoid a specific "outcome" and present players with an "influence diagram" showing how the model predicts their decisions will echo through the region's network of relationships and dependencies. This would leave the players responsible for using the model's relationship network to make their own, better informed, decision.

Support to the opposition or threat

The opposition in a game can be managed by a separate group of opposition players, or it can be managed by control. Either way it is important for the threat's behavior to reflect reasonable reactions to player decisions. When military actions are involved, the course of action for the opposition may be clear. However, when public or leadership reactions are involved, it can become less clear what will happen, particularly if cultural or national experts are not available to provide the benefits of their expertise. An ST model of the PMESII interrelationships within a country, or region, will provide those playing the threat with a more consistent way to gauge plausible or likely reactions. Because the ST approach inherently emphasizes the interrelationships and linkages in decision-making, then the actions or attitudes of the threat can be more nuanced than those produced by more standard analytical models, and can occur in a broader context than if they were simply decided on by control.

For example, in our Pacific scenario, suppose control needs to assess the reaction of the Japanese public to a North Korean threat to attack U.S. airfields on Japan. An ST model of the Japanese political process could identify the various influencers that would be accounted for in any change in attitude, ranging from the Japanese political parties to various assurances by the U.S. government. Previous actions that may have reinforced the political position of one party or another, such as relaxing a ban on U.S. beef imports, may in turn influence the overall reaction to the North Korean threats, even if they did not occur during the same time span, and superficially may appear to be unrelated.

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Using games to support ST model design

While nothing will actually "validate" a model as subjective and socially based as an ST model, it may be possible to understand better whether the ST model accurately reflects perceptions of the problem it purports to represent. At the most basic level, using a game to test the ST model will involve somehow comparing the model to the game. As is the case with using an ST model in the design and execution of a wargame, there are several ways to use gaming to understand how well an ST model is working—these fall into two general groups: design tests, and execution tests.[49]

Design tests

In this class of tests the process of wargame design is used to test or refine an ST model. In other words, these "tests" represent the game designers coming up with concepts, in collaboration with or independently of, the ST modelers. The results of what the designers do are then compared to what the ST modelers have developed.

Thus the most important relationship is the one between those who are testing the model and the ST model designers. The relationship can be collaborative, where everyone is working together on the problem, or it can be more distant, ranging from competition to completely blind tests where the designers work independently from the modelers, comparing their efforts only at the end. Which type of technique you choose will depend on the overall objectives of the effort; blind tests work better for testing a model, and open tests (where the modeler is involved) work better to refine and add to the model.

49. There is a temptation to call these "play tests" however the play test is a term of art in game design and using it here risks confusing this discussion with one on how games, in particular commercial games, are tested prior to production.

For these tests, several options present themselves, including ones where the game designers and ST modelers collaborate, ones in which the game designers and modelers compete, and a blind test in which the game designers try to duplicate the ST model in their design.

Collaboration

ST models can be examined in the game design process by the game developers and ST modelers collaborating on a game design. The game designers are given a problem, and they work with the ST model's designers to identify all of the internal and external variables involved, then collect and process the data they need to assemble the game. At the same time that the designers are working on the game design, the ST modelers are using the information collected as part of the design process to build an ST model of the key elements of the game. Working together both sides can share insights into key feedback and feed-forward processes, identify important variables, and raise issues that need to be examined through the game scenario. Because both the game designers and the ST modelers are working on the same problem, the ST design should gain from the insights of the gamers (and the game design should in turn benefit from being encoded into the ST model). This is not a "validation" process but rather one that uses the insights developed by the game designers to further refine or define the ST modeling process.

As a variant of the case where the game designers use the ST design to help them develop the game, this is perhaps the most straightforward one to implement. Because the game designers are for the most part simply receiving additional assistance from the ST model and ST model designers, there should be little resistance on the designer's part. In this case the game designers refer to the ST model for game development ideas, which they then discuss and elaborate on with the ST model designer. If the game designers disagree with the model developer, the model developer should focus on the processes and concepts underlying the disagreement—that is, the links and associations and feedback loops being constructed by the designer—instead of any factual or conceptual disagreement. It is possible that the game designers are taking a different approach toward the problem, one that might benefit the ST model; it is also possible that the designers have identified an entirely new set of relationships that may need to be incorporated into the model.

Returning to our Pacific game, designers constructing a board game to illustrate the effect of various actions in the region would need to account for potential actions by various other powers in the region. Assuming the primary powers were represented by the players, it would be important to incorporate freedom of action that might disrupt U.S. interests or actions in the region. For example, a strong emerging relationship between Japan and China, while perhaps unlikely and thus expensive for the Chinese and Japanese players, would have significant political and military effect on the southeast Asian countries. As such, this possibility would need to be represented in the overall game design. While the ST database may not have predicted a Chinese-Japanese alliance, it might be the first thing a game designer thinks of because it would be one of the most potentially disruptive actions to occur in the game. Observing this, the ST modeler might ask what incentives the two countries might have for forming such a relationship (historical memory, competing interests, domestic politics, etc.), and what constraints may act against it. The ST modeler could then incorporate those incentives and constraints into their model's processes.

Competition

In contrast to the collaborative approach, a more competitive way of using gaming to examine an ST model involves the ST modeler's constructing a “shadow” game design at the same time that the game designers construct the actual game design. Game designers would proceed to develop objectives, which would be shared with the ST modelers, but then the groups would diverge. The ST modelers would attempt to understand and answer the objectives using an ST model, while at the same time the game designers would develop the game. As we envision such a competitive process, the game designers would have access to the ST model and its background information, so that any divergence between the two efforts would result from the additional thoughts of the gamers, as opposed to their missing something important from the ST model.

While developing their game, the designers would keep track of key relationships, feedback loops, and other elements that would be natural components of an ST model. At the end of the design process, the two different efforts would be compared, with the difference potentially influencing the ST model development (as well as enhancing the game design).

For example, in the illustration of a Japan-China alliance we used earlier, the ST modeler would not be involved in the game design until after its completion. Game designers would record their key ideas and conversations, one of which would address the possibility of Chinese and Japanese players forming an alliance. Assuming that the result of the designer's discussions was that this is unlikely in the real world, there would have to be constraints in the board game design in order to make it expensive and difficult for such an alliance to occur. (Remember the board game design has to be executed without use of controllers.)

The board game design restricted players' actions by imposing costs on domestic political will, as well as identifying special trigger events, such as U.S. withdrawal from Japan, that changed the overall calculus in the region. Since none of the experts used by the ST designer had identified even the glimmer of a possible Japan-China alliance as realistic, the ST designer did not consider all of the other constraints that the game designers had to consider.

Likewise, the game designers, when they used the ST model, had to extract a couple of important sub-elements of the model to incorporate into their game, but did not find the overall model helpful with this problem. When presented with the designer's problem, and the collection of actions they had taken to resolve the problem, the ST modeler was able to identify several different constraints and linkages that had not previously been identified in ST model development. Also, the subroutines used by the gamers were thus identified as key linkages in constraining state actions in the game, and thus would need to be re-examined by the ST modeler in that context.

Blind test

The blind test is a variant of the above competition model, except that the focus is on the game designers, and the ST modeler is mainly observing the designers. This test is blind, but only on one side. The designers are the "lab rats" being studied by the ST modeler to identify any gaps in the ST model.

In this case the game designers are given their objectives and go about their business under the careful observation of the ST modeler. The ST modeler has the responsibility of identifying key issues and gaps that arise during the design process, and seeing how those are reflected in his ST model. He does not help the designers; rather he is an impartial observer. Otherwise the identification of various ST model elements included, or not included, in the model proceeds as in the case of the competition process.

This version has the potential to be the most rigorous version of all of the various ways to test the ST model described so far, because here the ST modeler can be removed from the equation and an impartial observer substituted. The observer would be responsible for watching and reconstructing the game design process while simultaneously taking apart and understanding the ST model process. Such an observer would have an opportunity to use the deliberations of the designers as another input into their understanding of the ST model, and, at the end, they would produce a critical review of the ST model.

Execution tests

While ST models may be closest in nature to the actual game design, and thus more likely to be understood and tested in the design process, it is also possible to test the ST models during play of a game. In order to test the ST model it must be compared to something. We do not want to compare the model to something that is an internal structure or assumption of the game; those arise from the actions of the designers, and evaluating them would better be done through a design test. Instead we would like to compare the ST model to processes that derive from factors outside of the game design. In a game, there are two primary sources for real world information about subjective processes: player decisions and subject matter experts. In this section we will discuss deriving ST model information from both of these sources.

Player decisions

Player decisions drive game outcome and flow. Comparing the game flow, player decisions, and outcome to the ST model can provide an estimate as to how well the ST model mimics the details of the internal processes the players are trying to simulate in the game. Because the players are often experts in their internal processes, the game will present a unique opportunity to observe internal bureaucratic processes at work in a controlled and accessible (both in time and space) environment.

In order to test the ST model against player internal decisions and organization, the following elements are necessary:

- A game design that imposes the right political and social organization on the players. If, for example, the simulation models the Pacific Combatant Command, then the players will need to be organized in the game according to how PACOM is organized. Likewise, they will need to be given the same or similar motivations and goals as those organizational components.
- Data collection that identifies not only what the players did, but how they arrived at their decisions. What were the agendas of the individual sub-components of the decision process and how did they influence the outcome of the overall organization? For example, a key factor in a game decision may have been a hallway conversation between someone down in the chain of command and the senior commander. Without a record of that conversation there will be no ability to compare the model with the game for that decision.
- A modular understanding of both the game and the model. By modular we mean that there has to be a mapping of the internal processes at work between the model and the game, with an understanding developed as to which processes from the model are reflected in the game.

In examining the requirements for testing a model of internal processes, it becomes apparent that a large-scale, Title X-style game will offer the greatest amount of information for comparing the model. A Title X game, with 50–100 players, a complex scenario, and a detailed simulation of the overall chain of command, can allow an internal ST model enough interaction between players and the organizations they represent to test the model's construction of the internal relationships. If the model focuses in detail on one particular command or sub-section of the overall U.S. chain of command, then that section can be represented in greater detail in the overall simulation, or a separate game will need to be run.

An ideal test environment for an ST model would be a game in which each critical node (as represented in the game) is managed by one or more players familiar with the political and social culture of that entity. Thus to test a COCOM game, you would want to have representatives from the component commands who are familiar with service policies and agendas, as well as representatives from regional and subordinate commands who might be tasked to conduct operations.

Capturing player decisions in the context of a large-scale game would require considerable investment in analysts' time. It would, however, provide the opportunity to document internal organizational processes, as represented in the game, and compare them to the way the ST model represented those processes. For an ST model that is designed to portray those processes this would be virtually the only opportunity to compare how the model works with reality, short of observing a real-world operation. In a real-world operation, however, the nodes, communications, and personnel involved quickly become so spread out and vast that the artificialities found in the game may provide more of the kind of data needed[50] to verify the model than could be obtained from even the best documented real-world event.

50. Such as the goals and objectives of internal, subordinate, organizations.

Subject matter experts

If the objective of an ST model is to describe primary external processes, such as the threat, other nation states, or populations, then examining player actions and decisions in a game will not necessarily provide much insight. Just as an ST model can draw on subject matter experts in its design, games can provide a venue for stimulating those same SMEs with a scenario, and comparing the results to the predictions from the model. The type of game that would be most useful for this kind of comparison would be the small to medium (10–50 players) tabletop wargame. There, players representing the various organizations involved would get a chance to discuss the issues in the context of a particular scenario. ST model creators would need to help design the scenario and facilitate game play in order to ensure that key processes in their model were discussed during the game.

Using our Pacific game example, the tabletop might concern relations between China and Japan in the context of expanded oil exploration in the Spratly region. Experts would play China and Japan, as well as other regional players and the United States. The game would evolve through a series of pre-scripted events, ranging from aggression to proposals of business relationships between the parties involved. Players would be asked what factors would play into the decision-making by senior leaders in those countries. Those factors would be compared to feedback and feed-forward loops present in the ST model. In fact, ST model runs that included scenario elements along with player decisions and guidance could be conducted as the game progressed. Players could be presented with the model results, which would be used to stimulate further discussion in the game.

Once the game had been played through in a paper and pencil format, it could be migrated to a web or stand-alone, computer-based game. This game could use inputs from the ST model to represent processes in the game not played by the players, such as threat countries, or parts of the component organization. Once computerized, multiple analytical options would open up to the ST model designers, including using the game with real-world participants from various countries and commands, to allowing a range of SMEs to participate.

These runs of the game could occur asynchronously and with players participating from separate locations. The results of the runs could further serve to refine the ST model, with the possibility that various programming methodologies could then be employed. Examples would include construction of autonomous agents to represent various nodes in the game, or the use of various neural networks to reinforce or diminish linkages and processes in the game. This sort of "programming" could be done with human players, or it could incorporate autonomous agents playing in multiple iterations.

While the automation of ST model evaluation is beyond the scope of this paper, a boardgame design provides a way to begin constructing the interface and structure for such a process.

Cautions about using ST models in wargames

Any consideration of ST models and their incorporation into wargame design or execution should take into account the liabilities inherent in the reliance on models for wargame execution. Depending on the point of view as to whether games are a storytelling or decision-making form, when models are misused in games they can interfere with the basic operation and action of the game mechanics. Some of the pitfalls that may be encountered in using models, including ST models, in games include:

- Substituting model results for player decisions. Games are about decisions, and incorporating human actions into the course of events. When models are introduced they often become a substitute for this, with both players and control valuing the model outcomes more than the player contributions.
- Belief in the accuracy of the model results. Just because the model—particularly a PMESII model—has been validated, that does not mean that it is capable of accurately predicting real-world outcomes. Instead, the model describes important relationships. When used this way it can contribute to control and player understanding; when equated with reality a model can allow both players and control to substitute its results for their own judgment—to the detriment of both.

- Disrupting game play. Models, for all their utility in games, also represent a serious threat to control's ability to manage players. Models, whether available only to control or shared with the players, introduce a separate and independent authority into the game. In games where you already have subject matter experts, experienced players, nervous sponsors, and others commenting from the sidelines, the new authority can be used by various groups against other groups, or control. These disagreements can be even more difficult to settle.

An example game

Throughout this paper we have been using a notional game about engagement and alliance building in the Pacific region as an example to illustrate various options. Here we would like to bring some of this discussion together to provide a means of illustrating how such a game design might be used to further the development of an ST model.

Our game objective is to design an easily replayed board game of the strategic situation in the Pacific region so that a variety of scenarios and commanders' engagement options could be tested. Why choose a board game? Because the “standard” means of examining an ST model would be to use SMEs in the context of some form of seminar or large-scale game. We choose the more non-standard approach in order to illustrate that any sort of game design can be used in conjunction with ST models, and also because board games can form the initial design basis for moving to the next level—an integrated ST model “back end” combined with a computer-based “board” game front end.

The game designers would typically begin by identifying key processes that create and resolve conflict. Economic necessity, national prestige, territorial ambitions, and historical and cultural issues might be some of the reasons that conflict would occur. Means of resolving the conflict would range from military action, to forming alliances, to various types of engagement operations (humanitarian aid, conferences, cultural exchanges, etc.). The key goal would be to map out how these actions and processes relate to one another—for example, if moving aggressively on exploration might trigger military conflict, and how cultural or humanitarian exchanges might mitigate that conflict. Mapping these processes could easily draw from existing ST model blueprints from the region; however, it is likely that game designers will have their own “take” on how players might act in various situations, as well as how known processes and positions of players in the region might need to be represented in the game. By giving the designers their ST model of the Pacific, the modelers would ensure that at least part of the design incorporated the model. They would also be able to look at what the designers chose to include, or not to include, in the design—which might tell them something about their model, and how the designers evaluated it.

As the design progressed it would be important to construct representations of how various sub-processes worked. The ST model subroutines for various loops and relationships would again be a source for the designers. However it is likely that the designers would need to create additional processes, and abstract some processes that the ST model represents in detail. At this point the ST modelers might work with the designers to ensure that key aspects of the ST model design were incorporated into the game, so that when the game was played, the ST model would be reflected in the players decisions. Ultimately aspects of the actual model, or the model itself, might be incorporated into the design. It could be done to facilitate execution, or to decrease design workload in various areas.

Once the game should be finished, results of playing the game could be compared to ST model results. If, during the development of the game, particular decision-nodes should be identified that were common to both the model and the game, multiple repetitions of game play could provide insight to the modelers about those nodes. This would be especially true if the model were simulating a process that the players were embedded in, or if SMEs were playing the game and the game represented threat processes.

Suppose, for example, that the players in the game represent different components, task forces, or staff codes of the Pacific Command. The objective for each game "move" is to design an engagement plan for the theater that would successfully carry out command objectives. Players with Pacific Command staff experience might accurately reflect internal processes and decisions about how to structure such a plan for the theater. Likewise if SMEs represented the "opposition" in the game (China, India, Japan, Indonesia), their reaction to the plan, and potential counter-moves, could be compared to the same opposition processes postulated in the ST model of the region.

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