EXAMINING FORESTRY POLICIES WITH SYSTEM DYNAMICS METHODS

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ABSTRACT

This paper describes the use of system dynamics methods to examine forestry policies. The important results are a change in the question posed by forest managers and the use of white boxes to make assumptions explicit to all interested parties. Behaviour of people is improved because complexity is reduced and communications for all interested parties are improved.

1. INTRODUCTION

The questions being asked by system analysts of forest management teams are: "How much timber, cash flow, water, wildlife habitat, recreation opportunities and other benefits do you want to produce? What are the relative monetary values of the benefits? What are the interaction coefficients and production functions for each mode of silviculture?"[1,2,3,4,5,6] The method described here uses a different question: "If a particular mode of silviculture is applied, what will be the production of biologically possible combinations of benefits over time?" This question is asked by and not of the management team.

This different approach focuses attention of all interested parties on the biologically possible combinations of benefits. The choice by consensus of this or that combination of benefits establishes a single goal for silviculture.[7] This goal is to transform the forest toward the dynamic state of organization that produces the desired combination of benefits. The goal integrates cultural actions in all functional areas such as timber, water, cash flow, wildlife and recreation. Complexity in the decision and control processes is limited because large numbers of simultaneously changing variables are integrated to display a few biologically possible alternatives.

A relatively simple model, called DYNAST, jointly frames and displays sequences of outcomes for evaluation (figs. 1,2). Complexity for the mental model is limited to successively dividing groups of displays into two classes – acceptable and not acceptable – until the final choice is one of two options. Complexity for the mental model is always 1 or 2.[8,9,10]

Advantages for individuals and organizations are: (1) relatively simple evaluations are made by the mental model of a limited number of options; (2) a reduced cognitive strain is placed

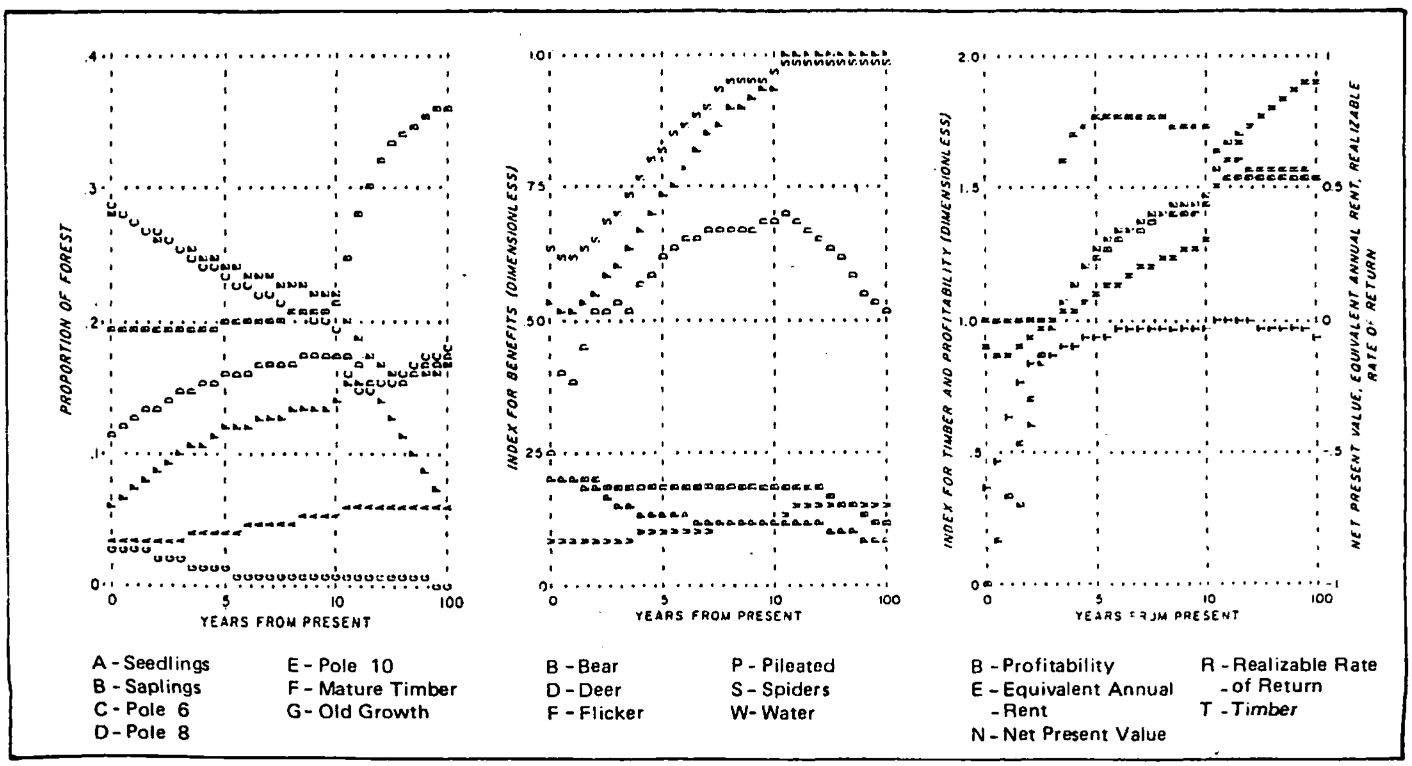

Figure 1: Consequences of regulating the Big Ivy forest with an 80-year period of rotation.

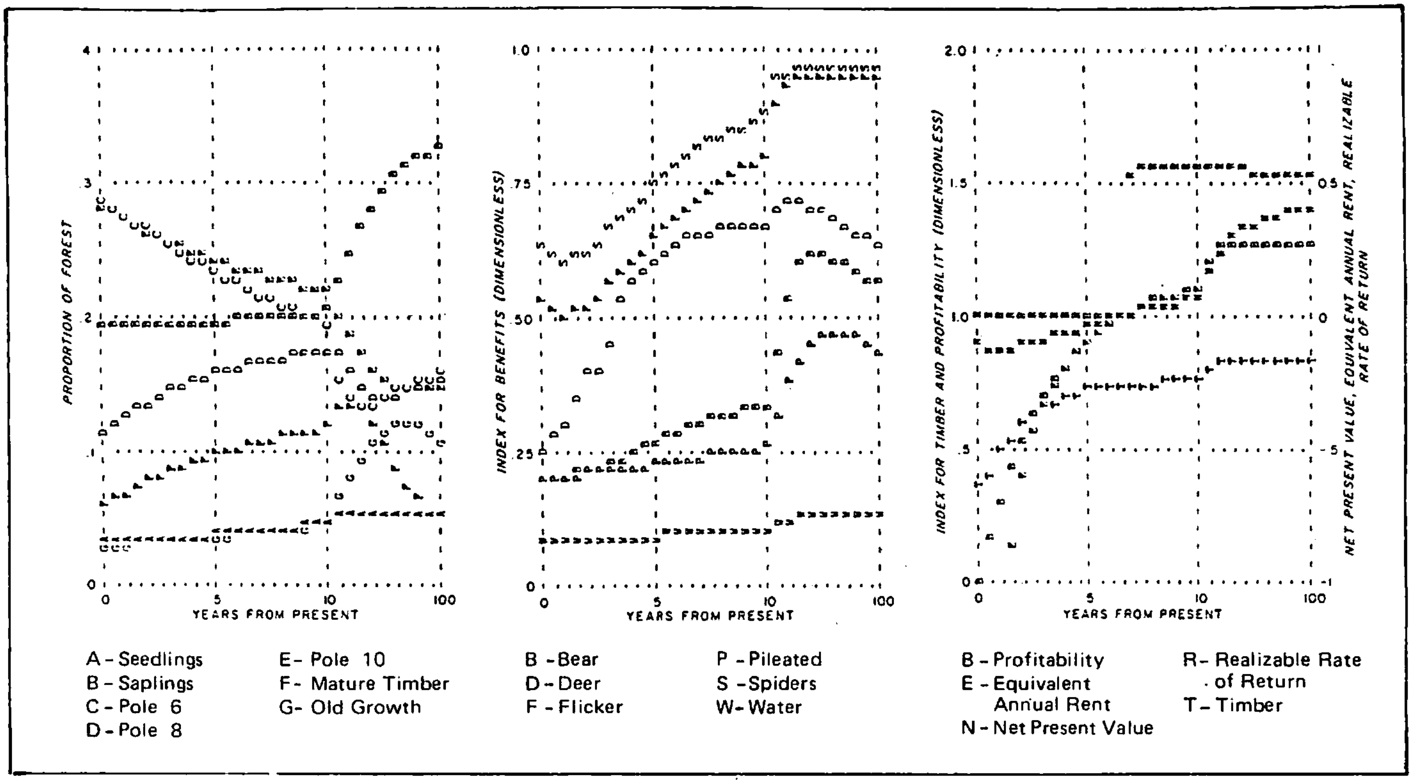

Figure 2: Consequences of regulating the Big Ivy forest with superimposed rotations; 80 percent is rotated through an 80-year period and 20 percent through a 200-year period.

on managers and individuals; (3) included in the decisions is information from professional training, personal experiences and perceptions that consequences are casually linked to acts; and (4) perceptions of self-interest by all interested parties are given due consideration.[10]

2. THE SYSTEM DYNAMICS SOLUTION

System dynamics methods are used to place the question "If this, what then?" in the context of decision and control processes. These processes are viewed as a repetitive cycle of three events: assembling information about the state of a system; using one's mental model to make decisions about the system; and using controls to bring the system to desirable states of organization. The diagram, figure 3, illustrates how the system dynamics model, DYNAST, links the decision and control loops.

The state of forest organization is sensed by frequent inventories of stands, timber volumes, animals and plants. Responses of the forest to cultural actions are monitored, and research is designed to explore linkages between consequences and silviculture. This information is used to keep DYNAST congruent with the forest.

The "projections" are displays of answers to the "if" question. These charts (figs. 1,2) and tables transmit to all interested parties combinations of benefits for alternative modes of silviculture. The question "If this, what then?" is modified by parties in the decision loop. Model parameters such as the rates of timber harvest, sizes of openings formed, and conversions of forest types are changed until a desired combination of benefits is projected. Any party can be creatively

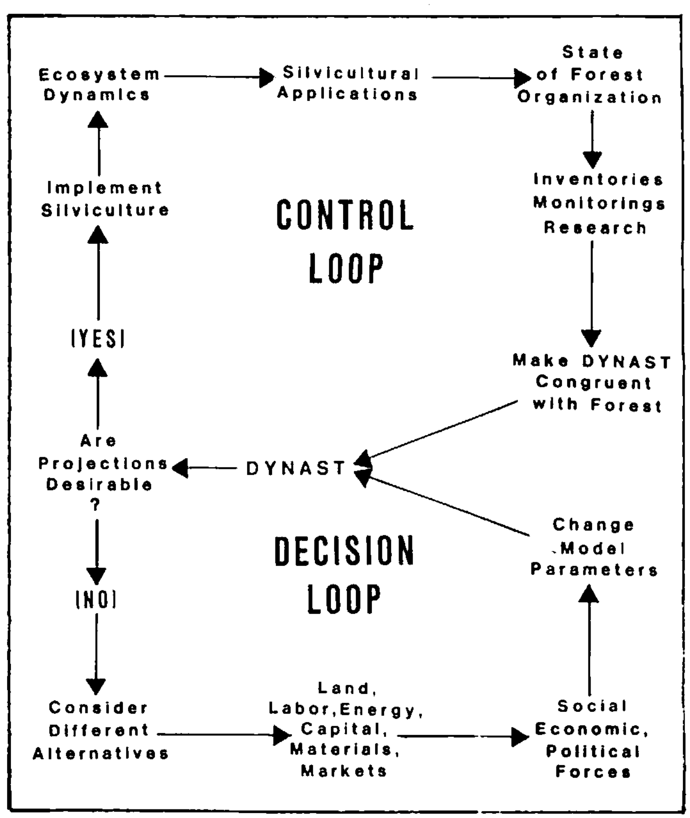

Figure 3: Diagram illustrating how the system dynamics model, DYNAST, links loops which are external to the computer model.

involved by asking questions about the displays of benefits. For the display in figure 1 a question could be: What would be the stream of benefits if harvest age were 120 years and size of openings were 5 acres? For figure 2, a question would be: What would we have if 50 percent of the area were harvested at 90 years of age?

The goal for managing the forest comes from outside the system and is determined by social, economic and political forces. These forces operate through the availability of land, labor, energy, capital, materials, and markets. Within the decision loop all interested parties participate in examining the projections of expected benefits. These projections are the basis for considering different alternatives or for deriving a consensus. A consensus results in activation of the effectors, in this case the mode of silviculture that was used in the control variables to project the combination of benefits selected by the parties.

The biological potential for each combination of benefits is determined by ecosystem dynamics. As silviculture is applied to transform the forest through a stream of states of organization, the desired combination of benefits is produced.

WHITE BOXES. Graphs, called white boxes, are used in the DYNAST model to change behaviour of people in the decision and control processes. "White boxes" is the name used to emphasize the difference between them and the black boxes of many computer models for resource allocation.[4,5] In this approach, the white boxes, which are used as table functions, have several positive advantages: (1) they improve communications among managers, specialists and other interested parties; (2) they link the specialists in functional areas to interdisciplinary teams; and (3) they provide a way to explicitly display relationships and suppositions for scrutiny by all interested parties.

Managerial decisions in forestry derive ultimately from the values of society, mediated through the judgment and insight of managers and the institutions they represent. The white boxes enhance these processes by integrating more information than would be used normally and by communicating the relationships in explicit forms. White boxes are a way to include professionals in functional areas such as silviculture, economics and wildlife in the decision and control process.

The procedure is to translate large amounts of both quantitative and subjective information into white boxes which serve as signals for explicit communication.[11] Behaviour in the decision and control process is improved. An example is the algorithm for projecting the potential livelihood for white-tailed deer in the Appalachian Mountains of North Carolina.[12]

From publications, wildlife biologists, hunters and forest managers information is collected about the potential livlihood for deer in the Southern Appalachians. Suppositions are developed for the most important variables that are to be used in an algorithm composed of 3 white boxes.

Supposition 1. – An increase in the area of seedling stands from 0 to about 7 percent of the forest increases the availability of high-quality browse and soft mast.

Supposition 2. – An increase in the area of 10-inch pole and mature timber stands of hardwoods from 0 to about 40 percent of the forest increases the availability of hard mast.

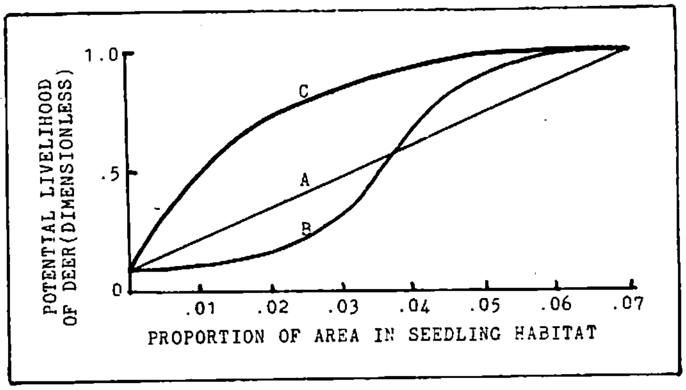

Figure 4: Illustration of a white box which displays explicitly relationships for scrutiny and adjustment by all interested parties. Lines A, B and C are alternative wave forms that may be supported with information from different sources.

Supposition 3. – The area of the stands influences the dispersion of forage, mast, and cover, and influences the utilization of the forage and mast. An intermingling of small, diverse stands is beneficial for the potential livelihood of deer.

Some other consideration could be included, but for purposes of illustration these three suppositions are adequate. The next step is to transform these suppositions into quantitative values that can be interrelated over time and can be related to management actions.

Seedling stands are defined as stands 1 to 5 years old. If the forest is harvested on a 100-year rotation, about 5 percent [(5 years/100 years) x 100] of the area would be kept in seedling stands. Changing the rotation length changes the proportion of area in seedlings which is the primary source of browse and soft mast. The shorter the rotation the greater the browse, but very short rotations reduce area occupied by the 10-inch and mature stands that provide hard mast. From information about browse, soft-mast, and hard-mast production, the rotation periods must be at least 70 years. This requirement establishes a maximum area in seedlings at 7.1 percent [(5 years/70 years) x 100]. A larger area in seedlings does not improve the potential livelihood for deer in this forest. This relationship is expressed quantitatively with a white box (fig. 4).

The contribution of browse to the potential livelihood of deer is maximum, that is, has a value of 1, when 7 percent of the area is in seedlings, good-quality browse declines to a very low value and the contribution of browse to the livelihood of deer declines to 0.1 when there are no seedling stands. The direction of the curve is not in contention; the exact shape of the curve is unknown. A straight line can be used to connect the established points, line A, or, more realistically, a sigmoid curve, line B, is more likely to reflect the behaviour of biological systems. What is important is that the waveform integrate and communicate the sense of the original information; the direction and waveform of the curve and the limits, such as 1 to 7 percent in seedling stands. As new information becomes available, the waveform is adjusted to improve congruence between the white box and the forest.

Each white box is based on the best information available and is used to explicitly display relationships for scrutiny by scientists, managers, resource specialists in all disciplines and other interested parties. Any participant can ask how a change in the waveform might affect the outcome of a decision. For example, a resource manager may have evidence for a waveform similar to that of curve C (fig. 4). The effect of this change on the decision procedure can be examined with charts similar to those in figures 1 and 2. In this way monitorings, inventories, research and personal experience, over time, adapt the waveforms of white boxes to a specific forest.

Similar thinking is used to transform the second and third suppositions into white boxes. Simple arithmetic is the computational procedure for linking white boxes. These computations as well as the information conveyed by the white boxes are important to administrators. This structure changes the mediation of values of society by integrating more information than normally would be used in making choices. The uncertainties presented by complexity and poor communications are reduced. The decision and control processes are improved; the mental model is aided.[8,9,10]

INTERDISCIPLINARY TEAMS. Organizations are interdisciplinary teams to co-ordinate the activities of different functional areas such as the physical, biological and social sciences. Performance of the teams is often slowed because of poor communications and lack of a common denominator to which the different functional areas can relate changes in variables. For example, timber values are related to the market prices for lumber; hunting values are not related to the market values of game killed. Choices, which are derived from the different kinds of values of society, must be mediated with a relationship that is common to benefits in all functional areas. There must be a common denominator to which specialists in different functional areas can relate volumes of timber, amounts of water, recreation experiences, and fishing opportunities. In forestry that common denominator is the state of organization of the forest.

As a forest is transformed from the present toward a future state, the common denominator for all benefits, including the amount of timber removed and the economic benefits, is the state of forest organization at each moment of time. States of organization are operationally defined as the distribution of stands by forest type, age, and area classes.[13] Called habitats, these classes of stands are places to live for all endemic plants and animals. Habitats for a forest type are meaningfully related to the potential livelihood of plants and animals, timber production, streamflow, and cashflows (figs. 1,2).

The choice of cultural actions is for all forest benefits produced in the aggregate. Aggregated benefits include nonmarketable values such as the potential livelihood for most endemic species. An analysis of the biological consequences need not attempt the impossible chore of allocating costs to each species or to each benefit. There is no need to attempt to evaluate the potential livelihood for all endemic species, also an impossible chore.

Since forests can be transformed from state to state, the goal for silviculture is a certain dynamic distribution of stands by various classes. This single goal is achieved by controlled rates of timber harvest, sizes of openings formed, and conversions of forest types. All silviculture is directed toward this goal.

This goal directs the attention of specialists in functional areas to the development of white boxes that are related to changes in the states of forest organization and are specific for each functional area. Complexity and confusion are reduced to the use of simple relationships that cross disciplines without conflict.

3. A SIMPLE MODEL

The first studies included investigations in functional areas, such as the biological potential for timber, water, and wildlife habitat production; the applications of silviculture; the functioning of interdisciplinary teams to resolve differences in demands by special interest groups; and the managerial applications of information and communication networks. These studies led to the discovery that structure in the existing functional areas discouraged communication among the interested parties and proliferated complexity for administrators.[14]

The need for a model that would use technical data in an understandable manner was obvious. The difficulty was in determining the model's role in decision making. An encompassing model would have to include suppositions about the behaviour of mental models for diverse, interested parties. It is very difficult to discover and project the dynamics of someone else's mental model;[9] the structure is not visible and perceptions of the forest and its responses vary widely. The conclusion was that the most important negative feedback loops in the forestry system were in the communication networks that led to the choice of a series of cultural actions and in the communications networks that professionals in the functional areas used to apply cultural actions. These

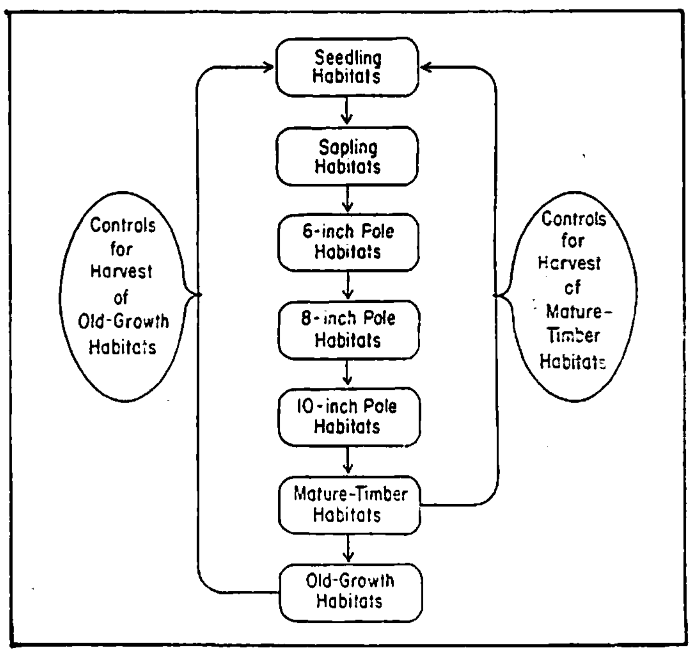

Figure 5: Diagram of the core of the system dynamics model DYNAST. This structure is repeated for multiple forest types; production of timber, wildlife habitats, and other benefits resulting from transformations in states of forest organization over time.

networks cannot be discerned and mathematically modeled to be congruent with the real forest because the behaviour of the system is dependent on in-place decisions of mental models over time.

The study plan was changed to develop a simple model that would link the decision and control loops. This model, DYNAST, simulates the familiar responses of a forest to silviculture (fig. 5).[15] When a forest habitat is harvested, natural or artificial regeneration establishes a seedling habitat that will transform through size classes of trees at a rate that can be predicted with some accuracy on the basis of many years of experience.

The model is started with information from an inventory of the real forest. Feedback loops in the model determine the rates of harvest that are to be used in the real forest to transform it toward the desired state of organization.

The transformation is relatively easy to direct by scheduling the rates and areas of timber harvest and by controlling the species regenerated. Random dynamics in large ecosystems limit the precision of prediction and control, but the model reflects the degree of control that forest managers can exercise. The pattern of harvest, followed by relatively predictable succession through age classes, can be used to create a certain state of organization of the forest – a proportional distributional of stands by age, area, and type classes. And, the state of organization, or distribution of stands, largely determines the kind and proportion of benefits available from forest, such as timber, wildlife habitat, and cash flows.

VALIDITY OF THE MODEL. Are the options generated by the model valid and are they suitable for making logical choices?

The premises from which the options are derived are explicitly displayed as white boxes. Resource specialists translate relationships from the body of knowledge that forms their disciplines. These translations are made without preconceptions of interactions, preferences and trade-offs among benefits or functional areas. What keeps these translations valid is the explicit displays which can be challenged by scientists and resource specialists in all disciplines and by resource managers, decisionmakers, and other interested parties. Both scientific and subjective suppositions, such as insights about future rates, are displayed for challenges.

Each white box expresses in a quantitative statement something we know or believe, such as seedling stands are a source of browse and soft mast for the potential livelihood of deer. Each reflects the state of knowledge in a functional area and is independent of knowledge in other functions. The white boxes are dynamic, independent models for a unit of knowledge that is sufficiently simple to be easily understood, challenged, researched and validated. Yet, comparisons of the potential production of multiple benefits are made in the DYNAST model across all disciplines and over time because the common denominator for all white boxes is the dynamic state of forest organization. It is the validity of the white boxes that validates the options generated by the model.

4. THE RESULT

Decision and control for joint production of forest benefits can be improved by using a structure (fig. 3) developed with system dynamics methods. Use of a simple model to link the communication networks in the decision and control loops through the media of the white boxes and the projections of potential outcomes reduces complexity and improves communications for all interested parties. The structure of the decision and control system is changed from conventional ways to a new direction for forestry. The important changes are:

a. The key question changes from: What should the forest produce? to If this or that silviculture is used, what will be the benefits over time?

b. Decision and control processes are linked with a medium, the model, for interaction of all interested parties among themselves, with the real forest, and with social, economic, and political forces.

Behaviour in the decision and control process is improved because:

- Complexity for mental models is limited to 1 of 2 choices at a time.
- Improved communications among specialists enhances the performance of interdisciplinary teams.
- More information is used in the decision and control processes than with the previous "how much" question.
- White boxes rather than "black box" equations display relationships for scrutiny and modification by all interested parties.

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