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DERIVING A METHOD FOR EVALUATING THE USE OF GEOGRAPHIC INFORMATION IN DECISION MAKING

by

Holly Jean Dickinson

A dissertation submitted to the
Faculty of the Graduate School of the
State University of New York at Buffalo
in partial fulfillment of the
requirements for the degree of

Doctor of Philosophy

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Abstract

Deriving a Method for Evaluating the Use of Geographic Information in Decision Making

by

Holly Jean Dickinson

The research presented in this dissertation involves establishing the value of geographic information and its analysis in decision making. The discussion is focussed on the use of a Geographic Information System (GIS) in a decision-making organization.

A literature search was performed to discover methods used in Economics, Management Science, and Information Science to establish the value of information. It is concluded that prior to establishing value, it is first necessary to improve our understanding of how geographic information is actually used. However, to support empirical observations of use, there is a need for a more structured format than descriptive case studies. A modeling technique, capable of revealing where geographic information is critical in a decision-making process and the costs and benefits associated with that use, is discussed.

Specific characteristics of complex decision-making tasks are used as criteria in examining the applicability of various modeling techniques to this research. After a discussion of various techniques, Petri Nets are chosen. The ability of petri nets to represent geographic information use in complex decision-making tasks is shown through a case study in a forestry organization. The use of petri nets to attach and measure costs and benefits along each step of the process is presented at a conceptual level.

The specific objective of this research is to demonstrate (through an in-depth case study) that the use of geographic information and its analysis can be modeled in sufficient detail to pen-nit the identification of costs and benefits attached to all or part of the decision-making process.

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Chapter 1 - Introduction

1. Overall Research Area

One of the current research areas in the study of geographic information and analysis involves how information is used and valued. The fourth research initiative of the National Center for Geographic Information and Analysis is entitled "The Use and Value of Geographic Information In Decision Making." Its context is described as follows:

> The theory of the use and value of geographic information is poorly developed. However, economic, psychological, sociological, and other existing social scientific methods will be applied to this problem. The role of information in decision-making, the mechanisms and processes by which information is defined and utilized, and the economic theory of information must all be addressed. Economic value is a demand-initiated concept. 'Me desire to reduce uncertainty creates demand for information, yet its value is difficult to assess because of distribution of benefits, variation in the value of information by culture, location, and decision, and changing community standards" (NCGIA, 1988, p. 53).

2. Significance

There are some specific reasons for studying the use and value of geographic information. Other reasons may exist, but the following support this specific research. It is expected that a better understanding of the use of geographic information will:

1) improve the ability to establish the value of information,
2) support the continuing development of suitable analytical technologies (such as GIS software), and
3) support more efficient design of GIS implementations.

A better understanding of value will:

1) support the quantification of benefits derived from GIS use, and
2) support the economic evaluation of a GIS (for both pre-implementation justification and post-implementation evaluation for re-design).

3. Narrowing the Scope

The research in this document will focus on a subset of Initiative #4's research: the use of geographic information in terms of the use of GIS products. Studying the use of geographic information in a GIS context is much more tractable than studying the use of geographic information in all contexts. It is more tractable because the implementation of a GIS forces structure into the use pattern and encourages documentation of use. Also, if the design of the implementation is performed in accordance with current software engineering methods, the users are forced to think explicitly about what they do with the GIS products.

Even though the use of GIS products may not be representative of the larger set of other uses of geographic information, it should be a good starting point for this area of research. Therefore, for the remainder of this document, the "use of GIS" will be defined as the "use of geographic information and the analytical tools in a GIS implementation to support decision-making tasks."

4. Previous Work

Work to date in the area of use and value of GIS has consisted only of case studies. Case studies on use are very descriptive, but non-structured so it is not possible to compare across different studies. Many of these studies did not include descriptions of all uses of the GIS, but focused on the extremely successful (or disastrous) projects. Case studies on value have, for the most part, focused on cost-benefit statements. The benefits reported are mainly those attached to the "automated mapping" uses of GIS, and not to the spatial analysis techniques for "use in decision making." Again, it is not possible to cross-compare case studies. Furthermore, none of the studies deal with the full benefits of the GIS (i.e., representing the "use in decision making" benefits). It is this difficulty in determining the true value of information use that first aroused an interest in this research.

The difficulty in determining the value of information and information systems is not a new concept. In 1971, Emery stated:

> As information systems become more comprehensive and integrated, formal methods of analysis become increasingly difficult to apply. Joint costs and joint benefits often make it impossible to determine the payoff from any one subsystem. As the system begins to pervade day-to-day operations and higher level decision making, benefits become increasingly difficult to evaluate in monetary terms. Inevitably, then, we must rely on experienced judgment, as well as technical analysis, to make cost/benefit decisions. (Emery, 1971, p. 42)

The problem continues to surface in recent literature. In 1986, it was suggested that in-depth studies on the use of information be performed before the determination of value is attempted:

> Information itself and its value-in-use is at best only touched by such measures like time spent for reading and, time and money savings. In order to get any further, deeper analysis of the information use situations is certainly needed. (Repo, 1986, p. 381)

The suggestion for studying the use of information still continues:

> It seems that the case-study approach is the only means at the moment available for studying the value of information deeply enough. Data have to be collected from information work and individuals performing the work using several collection techniques (interviews, questionnaires, diaries, content analysis, etc.). (Repo, 1989, p. 82)

The above statements are not intended to be a complete review of previous work on the use and value of geographic information. Rather, these statements are presented to indicate that a need for further research in this area exists.

5. Formulation of the Objective

As stated above, the initial interest in this research involved determining the value of information. Therefore, the first step in this research was to search other bodies of literature for methods used to establish the value of information which could be evaluated for applicability to the use of GIS. This is the subject of chapter 2. The conclusions from the review, as discussed at the end of chapter 2, lead to the specific objective of this dissertation:

> to demonstrate (through an in-depth case study) that the use of geographic information and its analysis can be modeled in sufficient detail to permit the identification of costs and benefits attached to all or part of the decision-making process.

6. Definitions

Before continuing on to chapter 2, it is first necessary to set forth a number of definitions that will apply throughout the remainder of this document:

System = the meaning is taken from the systems-analysis literature, and will be defined as the "use of geographic information and analysis in a decision-making environment." This includes all components of the system such as the objectives, the actors, the resources and the constraints.

GIS = geographic information system.

GIS Implementation = a specific instance of a GIS within an agency (or set of agencies), which includes all the hardware, software, database, enhancements, and staff required to use the GIS software to support the agency's tasks.

GIS use = use of geographic information and the analytical tools in a GIS implementation to support decision-making tasks.

Information = data related to some problem-solving environment, represented in a meaningful format, and used to reduce the uncertainty within a decision-making environment.

Geographic Information = information which has a spatial context, i.e. is related to specific and/or relative locations, or attached to objects which occupy a spatial location, with the locations being referenced by a coordinate system.

Value of Information = the benefits received by having information available in a decision-making process which act to offset the costs incurred to provide such information, (i.e., value is the sum of all benefits minus the sum of all costs).

Analysis of Information = any transformations that information may be subjected to in order to make the information more meaningful to the decision-making task at hand; this includes both manual and automated transformations.

7. Organization of This Document

The research presented in this document is divided into the following activities:

- evaluation of methods for establishing the value of information (Chapter 2);

- evaluation of alternative modeling techniques on their applicability to modeling the use of geographic information and analysis in decision making (Chapter 3);

- testing the chosen modeling technique for completeness and validity in a specific agency (Chapter 4);

- conceptual extensions to the modeling technique to identify measures of costs and benefits that can be attached to the components of the model (Chapter 5);

- conclusions from this research and further work (Chapter 6).

Chapter 2 - Methods Review: Establishing the Value of Information

1. Introduction

The purpose of this review is to find methods to support the economic evaluation of a GIS implementation. Cost-benefit analysis is the economic method most commonly employed in any type of evaluation of proposed, alternative projects. It has already been attempted in the area of GIS (Dickinson, 1988), but problems exist in the empirical application of this method (Dickinson and Calkins, 1989). Since this is the problem that has led to the research of this dissertation, a brief discussion of cost-benefit analysis and its shortcomings will begin this chapter. The remainder of this chapter will review other methods for establishing the value of information that have been found in different disciplines. The literature reviewed was taken from an extensive bibliography compiled on the 'value of information' (Dickinson, 1989). Another major work used for reference is (Repo, 1989).

2. Cost-Benefit Analysis

Cost-benefit analysis is not particular to determining the value of information. However, since the immediate reason for establishing the value of information is to compare the benefits of GIS to its costs, cost-benefit analysis is the method often employed. It is important to recognize that before a cost-benefit analysis can be performed, the value of information must first be determined by other means.

Cost-benefit analysis does not lend itself easily to empirical applications in GIS. Cost-benefit analysis is an economic technique used to support decision makers in choosing between alternatives by allowing the set of alternatives to be ranked on a common scale. This technique involves measuring both the total costs and total benefits of each alternative. The result is generally in the form of a benefit-cost ratio (total benefits divided by total costs) attached to each alternative. The different benefit-cost ratios for all alternatives are then compared and used to rank the alternatives. In the justification of a GIS, the alternatives are usually limited to implementing or not implementing the GIS. In principle, the alternative with the highest benefit-cost ratio is then chosen. This assumes no limit on capital exists (i.e., the agency is willing to borrow enough capital to cover the costs of the alternative with the highest benefit-cost ratio). This technique also assumes that all costs and benefits of each alternative can be reported in the same unit of measure. Costs are almost always reported in dollar values. Therefore, only those benefits that can be reported in dollar values are normally entered into the cost-benefit equation.

However, many of the benefits of the use of GIS arc not easily assigned a dollar value. These benefits are known as intangible benefits and are often reported as 'better decision making,' 'better planning,' or 'better information.' It is believed that these intangible benefits offer higher value to the agency than do those benefits which are more easily reported in dollar terms (such as improved cost-performance or faster output of maps). Not including the intangible benefits would probably lead to a significant underestimate of the potential benefits of the proposed GIS implementation.

3. Economic Evaluation of GIS

It must be noted that economic evaluation of a GIS implementation is performed for one of two reasons: pre-implementation justification or post-implementation evaluation and re-design. If the only purpose of the economic evaluation is to justify the proposed GIS implementation against its expected costs, then a cost-benefit statement based on just the tangible benefits may be all that is necessary. However, if the economic evaluation is to support justification of a GIS against other proposed projects, then the exclusion of intangible benefits may be underestimating the true value of the proposed GIS. In other words, a listing of the benefits of the GIS must include the benefits associated with the use of the geographic information provided in the GIS implementation. Economic evaluations are also performed after GIS implementation. In this instance, the results are used to support re-design of the implementation to improve its value to the agency. Again, the intangible benefits should not be excluded from this type of evaluation.

4. Review of Methods

The problems discussed previously lead to the conclusion that inherent in the economic evaluation of GIS is the need to establish the value of information as it is used in analysis and decision making. For this reason, the first step in this research was to conduct a literature search for various methods used to establish the value of information. The areas researched include the economic, information science, and management science literature. Methods for establishing the value of information will be briefly explained, and then discussed in terms of their application to establishing the value of geographic information and its analysis. These methods do not reflect an exhaustive list, but rather reflect the most popular methods as well as those that show potential for use in the area of geographic information. Not all of the methods found in the literature had specific names. Therefore, a classification of methods was created for the purposes of this chapter.

4.1 Economic Approaches

Methods discussed in the economic literature for establishing the value of information are almost all theoretical in nature. They offer a conceptual view of the value of information, but are extremely difficult to implement in empirical research because of both the large amounts of data required and the number of assumptions that are included in each of the theories.

4. 1.1 Exchange Value Method

A popular economic method for establishing the value of any commodity is to look at the exchange value of a product. 'Me exchange value is based on the economic principle of supply and demand and the theoretical equilibrium that will exist between the buyers and sellers of a given commodity. The exchange value, then, translates to that price which an individual is willing to pay to obtain a commodity. This method was among the first to be suggested to determine the value of a GIS product, i.e., what someone is willing to pay for a map product is the value which they attach to that product.

While the measure of exchange value is theoretically sound, several reasons exist that make it in-applicable for determining the value of information in practical situations. First, the actual value of information to the buyer is not determined until after the information is purchased and its contents become known. A person may pay $ 100 for a data tape, expecting that the data will be of a value of at least $ 100. However, upon actual use of the data, he may find it to be of much higher value to him. Likewise, he may realize the information will not help him in his task, therefore reducing the value of the information greatly. Second, the exchange value does not account for repeated use of a piece of information. If a set of reports is paid for once, but used repeatedly, the exchange value does not reflect the true value of the information use. Finally, information is often a public good. A public good is a good which is not sold to individual consumers, nor does one person's consumption of a public good reduce the amount of good available to other consumers. Since information as a public good is not sold, no market transaction takes place, and therefore, no exchange value can be determined. Even in the event that an information product such as a map is sold, it is usually sold at a token price only to recover reproduction costs and therefore, does not represent a valid exchange value for the information. A recent study showing an attempt to include both the exchange value and measures of usefulness in the evaluation of a national map series is (Hoogsteden, 1988).

4.1.2 Decision Theory Method

A second approach found in the economic literature is the decision theory approach. This method is based on the concept of differing payoffs between a decision made without information and a decision made with information. New information will decrease the uncertainty of a decision-making process. The uncertainty in a decision is characterized by a set of uncertain states of nature with a probability distribution of their occurrence. The additional information will act to change these probability distributions and decrease the uncertainty. This changing of probabilities is sometimes referred to as bayesian updating of a probability distribution. Since the 'expected' payoff from the decision made is a function of the known payoffs and the probabilities of the related situations occurring, the value of the information is the difference between the payoff with the information and the payoff without the information. For a good example of expected payoff and bayesian updating calculations as well as decision tree diagramming, see (Emery, 1971).

To apply this decision theory approach empirically, one would ask three questions. "If we spend money on this information ..." (1) what additional surprises will result (and how often), (2) what decisions will be altered (for the better) if the surprise occurs, and (3) what is the effect on payoff from an altered, improved decision? (Emery, 1987 and Dickinson, 1989). One difficulty in performing an empirical study based on this approach is in collecting the large amounts of data for each decision to be made: the possible courses of action, the possible situations, the dollar values attached to all possible outcomes, the probability distribution over the possible situations, and the initial decision that would be made before the new information is obtained. Another difficulty is that the decision maker rarely knows how the new information will change his decision and his payoffs before he actually decides to purchase new information. This means that he must view what the information will tell him as yet another probability distribution over possible situations. Finally, this method assumes that one can attach a dollar value to any possible result, (combination of the decision made and the situation that occurs).

4.1.3 Multidimensional Attribute Method

The multidimensional value of information is the third approach that was found in the economic literature. This concept shows the transition from the product-oriented/exchange value found in the previously described methods to a value based on the actual use of the information. Economists such as Hirshleifer and Carter have developed lists of economically significant attributes of information such as certainty, diffusion affecting the scarcity value, applicability, content, and decision -relevance or timeliness, prior knowledge, prior information, accuracy, quantity, and power (Hirshleifer, 1973 and Carter, 1981). It should be rioted that these attributes are not directly measurable in empirical studies. Instead, the attributes are operationalized only by ordinal ranking schemes. Application of the method employs a questionnaire methodology. Information users are asked to rank information products on the different attributes. Since empirical applications of this method are found in the management science literature, it will be discussed in the next section.

4.2 Management Science Approaches

Empirical examples of determining the value of information are found in the management science and information science literature.

4.2.1 Six Methods for Reporting Intangibles

Emery suggests six techniques for reporting intangible benefits of information:

- quantify the benefit in non-monetary terms
- estimate the monetary benefits of an associated effect
- determine boundary estimates of benefits
- express the cost in break-even terms
- tradeoff with a tangible benefit
- use the cost of the lowest-cost alternative

(Emery, 1987)

Emery uses as an example, the intangible benefit of improved availability of inventory due to an increase in effectiveness from better information. A brief explanation for each suggested method follows.

The first method suggested by Emery is to quantify the benefit in non-monetary terms. He suggests translating the intangible benefit into a measure such as percentage change in stock availability or the change in delivery times. An adaption of this method for GIS purposes could include translation of an intangible benefit such as better management into savings of staff time spent making management decisions. This staff time savings could then be translated into a cost reduction in dollars spent in staff time on that decision (Dickinson and Calkins, 1989).

Emery's second technique is to estimate the monetary benefits of an associated effect of the benefit. Improved availability of stock may show a decrease in the amount of monies spent on expedited shipments necessary when the inventory is not maintained at a level equal to incoming orders.

The third method is to determine boundary estimates of benefits. These are subjective dollar value estimates based on the decision maker's experience. Perhaps even the 'worst-case' estimate is enough to justify the proposed project against its costs. On the other hand, if even the 'best-case' estimate of the value of benefits is not enough to cover costs, the proposed project will not be justified. It is important to remember though, that even subjective 'best-case' estimates of value may not correctly reflect the unknown value of an intangible benefit. Perhaps a better understanding of the use of GIS would improve the reliability of these estimates.

Emery's fourth method is to use the cost of a proposed project as the necessary break-even point for the benefits. For example, one could say that to justify the project, a certain percentage increase in sales would be necessary. If management is comfortable with a prediction that the required level of increase will occur, the project is justified. This method, however, does not support complete economic evaluation of a project, only justification against a set level of costs.

The fifth method suggested by Emery involves giving the decision maker an option between the intangible benefit and a tangible benefit. The decision maker could be asked which he would value higher, the intangible benefit or a certain dollar value of reduction in costs. This technique forces the decision maker to attach a dollar value to the intangible benefit.

Emery's final suggestion for reporting the value of intangible benefits is to use the cost of the lowest-cost alternative. If some improvement must be accomplished, and the lowest-cost alternative to the proposed project is $100,000, then the value of the proposed project meeting that new improvement may be set at $100,000. In reference to establishing the value of GIS, this method could be used when the implementation of the GIS allows an outside cost to be avoided. For example, when a project such as re-mapping of a county is mandated, the mapping agency may have the option of either implementing a GIS which could perform the re-mapping, or to contract outside the agency for the re-mapping. If the lowest outside bid is $300,000, and the GIS is able to create the same product, then one of the benefits of the GIS is an avoided cost of $300,000 (Dickinson 1988).

4.2.2 Questionnaire/Bi-Polar Questionnaire Methods

In other management science literature, Gallagher (1971) implements an approach similar to Emery's sixth suggestion. Gallagher establishes the perceived value of an informational report by asking the decision maker what would be the maximum amount he would recommend be spent for a report if it had to be obtained from a source outside the firm. This then becomes the value of the proposed project that would produce that report. In this particular study, dollar values estimated for an existing report ranged from $0 to $25,000 with a median of $550 over the 52 responses.

Gallagher also attempted to establish the value of that same information report through the use of a semantic differential technique. This is the empirical application of the multidimensional attribute concept. In this technique, a list of bipolar adjective pairs are used to represent the various attributes of an information report. These reports are ranked on each attribute on a scale of negative three to positive three. The following is a list of the fifteen bipolar adjective pairs on which decision makers ranked the information. The mean score and standard deviation for each pair over the 52 responses are included with the list.

Attribute	Mean	S.D.
informative-uninformative	2.08	0.86
helpful-harmful	2.05	0.96
useful-useless	1.95	1.10
desirable-undesirable	1.89	1.13
meaningful -meaningless	1.86	1.15
good-bad	1.85	1.13
relevant-irrelevant	1.82	1.19
important-unimportant	1.82	1.08
valuable-worthless	1.72	1.09
applicable-inapplicable	1.68	1.05
necessary - unnecessary	1.64	1.30
material- immaterial	1.54	1.15
responsive-unresponsive	1.47	0.97
effective-ineffective	1.43	1.30
successful- unsuccessful	1.41	1.11

(Gallagher, 1974, p. 52)

Munro and Davis (1977) used the same type of bi-polar questionnaire to analyze the relationship between the perceived value of information and (1) the method used to determine the data needs (top-down or bottom-up), (2) the nature of the decision making (structured or non-structured) and (3) the area of application (academic or administrative). The results showed the perceived value of information is not significantly different between the two methods used to establish information requirements; the perceived value of information is significantly different between structured and non-structured decision making; and the perceived value generated in one application area is significantly different from the other.

4.2.3 Simulations

Some studies found in the management science literature include the use of a simulator to create a particular decision-making environment. Through simulations, the change in decisions made without and then with information can be studied. The relative importance of information characteristics can also be studied with the use of a simulator (Dickson et. al., 1977 and McKendry et. al., 1971). Simulation of decision making forces control onto the environment. The simulator can be realistic only if the decision making is very structured in nature. Difficulty will arise when simulation of a very non-structured decision-making environment is attempted. From the literature, it does not seem that the simulation method has been widely used in determining the value of information.

4.3 Information Science Approaches

4.3.1 Cognitive Approach

Many of the criticisms of the economic methods found in the information science literature are based on the lack of analysis of the human factor. A suggested alternative is the cognitive approach. In the cognitive model of decision making, "subjective uncertainty is due to the lack of understanding of the cognitive structure of a problem at hand, not so much to lack of information" (Repo, 1989, p. 78). While this approach does introduce the role of individuals into decision-making evaluation, no suggestion of how value of information could be added into the model is made (Repo, 1989). Continuing to work with the cognitive model, Pratt suggests that "...studies should be conducted across many decision settings, examining various elements of post-cognitive structure, information processing, and decision performances as well as various characteristics of information systems" (Pratt, 1982, p. 204).

The cognitive approach is similar to the concept of value-in-use (Repo, 1989). Actually, Repo offers a dichotomy to the value of information: (1) the exchange value and (2) the value-in-use. "The value-in-use is that benefit the user obtains from the use and the effect of the use" (Repo, 1986, p. 375). There are three types of value-in-use: the subjective expected value-in-use (valuation of information prior to use, based on past experiences and expectations), the subjective value-in-use (valuation during actual use), and the objective value-in-use (the value of real effects of the information). This dual approach to the value of information seems quite useful for determining the value of geographic information. However, Repo argues that "the analysis of the value of information has not so far really reached value-in-use ... It is necessary to analyze more deeply the knowledge-work situations [tasks requiring knowledge] and the use of information in them before one is able to analyze the value of information to its user and for the use" (Repo, 1986, p. 377).

4.3.2 Decision Support Systems

It is probable that, in the near future, GIS software will include more modeling capabilities to support decision making (Densharn and Goodchild, 1989). A technology known as decision support systems (DSS) is defined as "Interactive computer-based systems that help decision makers utilize data and models to solve unstructured problems" (Spraque and Carlson 1982, p. 4) As GIS analysis and modeling techniques improve, it is expected that a new technology will emerge, known as spatial decision support systems (SDSS) (Armstrong et. al., 1986).

Current literature in the DSS area discusses the use of cost-benefit analysis and other methods to establish the value of a DSS. Keen (1981) states that the "traditional cost-benefit analysis is not well-suited to DSS. The benefits they provide are often qualitative... [such as] the ability to examine more alternatives, stimulation of new ideas, and improved communication of analysis. It is extraordinarily difficult to place a value on these. In addition, most DSS evolve...new facilities are added in response to the users' experience and learning. Because of this, the costs of the DSS are not easy to identify," (Keen, 1981, pp. 1-2). Also, since DSS is a form of innovation, it is an investment in research and development, not in a defined product.

As an alternative to cost-benefit analysis, Keen suggests a value analysis method for justifying a DSS. It involves the construction of a prototype DSS at a scale below the capital investment level, (i.e., a research and development exercise). 'Me benefits of the full system are then identified through the use of the prototype. The user asks, "what exactly will I get from the system?" and "if the prototype costs $ X, do I feel that the cost is acceptable?" If the user finds the prototype's costs acceptable, the costs of the full system are calculated. Then the threshold of value needed to justify that cost, and the probability that benefits to that level of value will occur are determined (Keen, 1981). The decision to implement the DSS is then based on the probability of the benefits justifying the costs.

Keen goes on to group the benefits quoted in DSS case studies into twelve categories, each labeled with respect to their case of measurement and the ability to quantify in terms of rate of return or payback figures:

Benefit	Easy to measure?	Benefit can be quantified in a 'bottom-line' figure?
Increase in number of alternatives examined	Y	N
Better understanding of the business	N	N
Fast response to unexpected situations	Y	N
Ability to carry out 'ad hoc' analysis	Y	N
New insights and learning	N	N
Improved communication	N	N
Control	N	N
Cost savings	Y	Y
Better decisions	N	N
More effective teamwork	N	N
Time savings	Y	Y
Making better use of data resource	Y	N

(Keen, 1981, p. 7)

5. Current Economic Evaluation of GIS

As stated at the beginning of this chapter, current economic evaluations of GIS implementations often use the cost-benefit analysis technique. A recent study of digital map databases characterized benefits into tangible and intangible benefits (Joint Nordic Project, 1987). With only the tangible benefits included in the cost-benefit analysis, the implementations did show a 1:1 benefit-cost ratio. Still, for a complete economic evaluation, it is felt that the intangible benefits must somehow be included in the evaluation. This view is also supported in the literature. "It is perfectly reasonable to judge most projects on the basis of their tangible payoffs, [such as cost reductions] but if an organization limits itself to these, it seriously inhibits the development of advanced systems" (Emery, 1971, p. 47). In a later article, Emery discusses the difference between improving the efficiency of a system or improving its effectiveness. Efficiency is "doing the thing right" and includes the tangible benefits. Effectiveness, or "doing the right thing," includes the intangible benefits such as value enhancement. He continues by saying:

> If management pays undue attention to the data processing budget [i. e., the tangible benefits] rather than net benefits, value-enhancing projects suffer a disadvantage in competition for resources with projects aimed at processing efficiency. This can have undesirable consequences, because most of the really significant improvements coming from information technology lie in greater effectiveness rather than increased efficiency. (Emery, 1987, p. 224)

Another reason for including intangible benefits comes from the economic concept of diminishing marginal returns. In other words, 'more is not necessarily better.' "The optimum system does not supply all useful information, since some information costs more than it is worth. Therefore, the specifications of systems requirements must simultaneously consider both the costs and value of information" (Emery, 1971, p. 18).

It has been established that unless a benefit can be put in monetary terms, it cannot be entered into the cost-benefit analysis. However, it has also been established that intangible benefits need to be included in an economic evaluation leading to a choice between proposed projects. Lay (1985) suggests a need for a systematic and consistent approach to handling intangible benefits so they can be compared across systems.

A recent suggestion is that the economic evaluation of a GIS be reported in three separate values: a benefit-cost ratio, a cost-performance calculation, and an order-of-magnitude estimate for non-quantifiable benefits (Dickinson and Calkins, 1989). The benefit-cost ratio would include all costs and all quantifiable benefits (except cost reductions). The cost-performance evaluation would include either cost reductions for a given level of performance or an increase in performance for a given level of costs. The order-of-magnitude estimate is similar to the decision theory approach. A dollar value is attached to a better decision and the contribution of the GIS to the better decision making is estimated. The percentage contribution of the GIS to the decision is then multiplied by the dollar value benefit to determine the value of the GIS. Even though this value is in monetary terms, it is suggested that it be reported separately from the benefit-cost ratio since (1) it may cause an overwhelming (and therefore, unbelievable) benefit-cost ratio, and (2) the confidence level of this estimate will likely be lower than for the other components of the economic evaluation.

While the above suggestion of three components to the economic evaluation is useful, it still lacks a method for determining the value of the information beyond the decision-theory approach which requires a dollar value be attached to the decision-making outcome. After an extensive literature search of his own, Repo concluded that:

> It seems obvious that there is not a single theory available which fully explains the value of information. This is because of the empirical fact that individuals give different values for the same information depending on the context. Information reduces uncertainty. Usually uncertainty is described in terms of probabilities. Useful as a general framework, it is not productive in practice because of the problems of getting data for the formulations developed. One should perhaps abandon mathematical formulae and collect statistical or descriptive data for empirical studies and then see if there is anything to generalize. (Repo, 1989, pp. 80-81)

6. Conclusion

At present, methods for determining the value of information do not seem practical for evaluation of GIS use. In agreement with Repo (1989), it is suggested that the next step in this area of research is to gain more knowledge of the use of geographic information and analysis through empirical observation of current use. In accordance with Lay (1985), this observation should be performed in a consistent and systematic way to allow comparison across various case studies. Since the immediate reason for observing the use of information is to gain knowledge pertinent to establishing the value of information, it is suggested that the observation be cast in the form of a structured, highly detailed model of the use pattern of information.

Since the intangible benefits of GIS use are associated with the use of the information in decision making, it is necessary to model the decision-making process in sufficient detail to understand the components of the decision-making system and the relationships between the components. (The reader is reminded that the use of the word 'system' refers to the overall decision-making environment, not just the information system.) A current view of decision making using GIS is at a high level of abstraction (Figure 1). We do not understand: (1) what happens within each of these boxes, (2) if the GIs represents one box or several, nor (3) how the geographic components relate to the non-geographic components of the decision-making system.

A highly structured model (instead of a descriptive model) will support the high level of detail that needs to be represented, as well as provide a framework for other case studies to follow. A highly detailed and structured model of use should also provide information on the contribution of geographic information and analysis to overall decision-making tasks. "Actual value-in-use can be identified if it is possible to trace the role of information for a knowledge-work task (subjective value-in-use) and isolate the impact of that particular information for the output of the task (objective value-in-use)" (Repo, 1986, p. 376).

The objective of the research to be discussed in the following chapters, then, is to demonstrate (through an in-depth case study) that the use of geographic information and its analysis can be modeled in sufficient detail to pen-nit the identification of costs and benefits attached to all or part of the decision-making process.

Chapter 3 - Modeling Decision Making

1. Introduction

In the last chapter, it was concluded that before we can successfully determine the value of geographic information and its analysis in decision making, we need a better understanding of how the information is actually used in these tasks. It was also concluded that empirical observations of use need to be represented in a more structured format than the currently used form of descriptive case studies.

A common method of representation used in scientific research is to construct a model of the real world observation. There is no single definition of a model since they can perform several functions in scientific investigation:

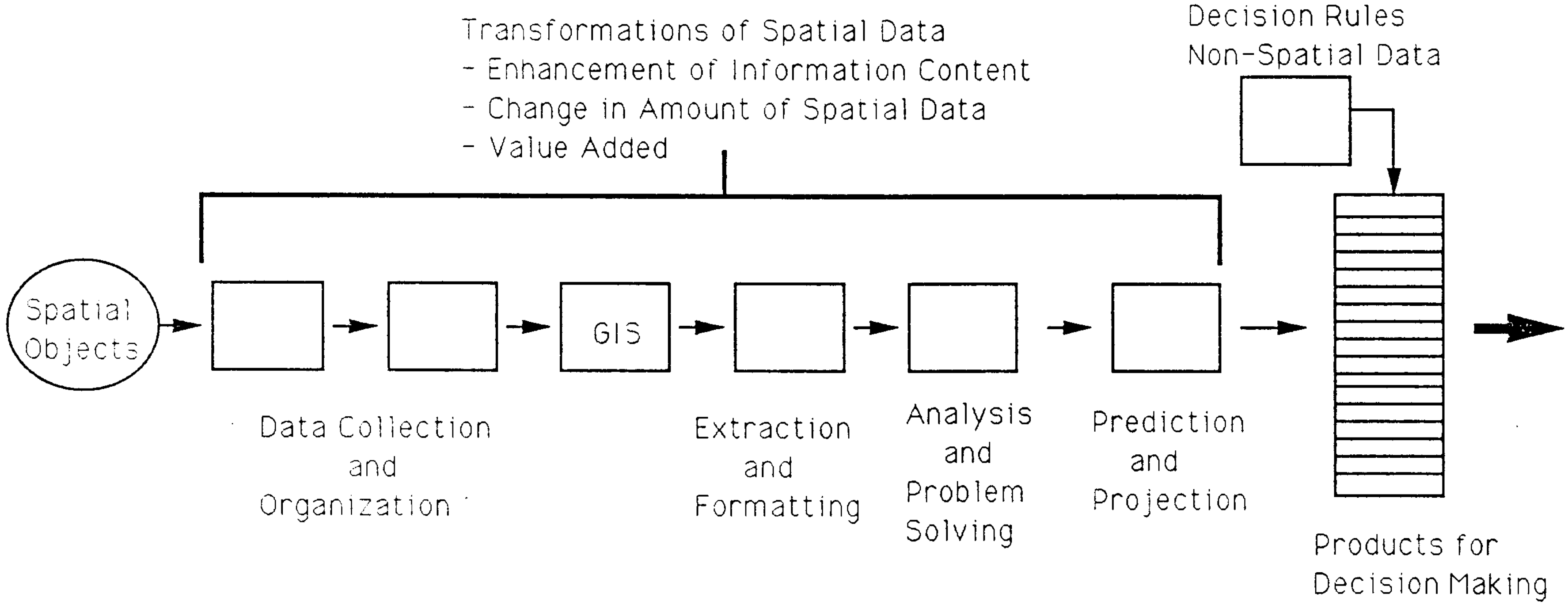


Figure 1. Organizational Use of Geographic Information in Decision Making (Calkins, 1989)

> A model may act as a psychological device which enables complex interactions to be more easily visualized (a kind of 'picturing' device); as a normative device which allows broad comparisons to be made; as an organizational device for the collection and manipulation of data; as a direct explanatory device; as a constructional device in the search for geographic theory or for the extension of existing theory. (Harvey, 1973, p. 141)

In this research, a model of a decision-making process will serve as a psychological and explanatory device (i.e., to aid in the understanding of how geographic information and analysis are used in the decision-making process). The first objective of this research is to develop or adapt a current modeling technique so it can be used to represent the use of geographic information and analysis in decision-making. Since the determination of costs and benefits is the justification for studying the use of geographic information, the model will also be used as an organizational device to analyze costs and benefits associated with this use. If the specific modeling technique is shown to work in the current case study site, it could evolve into a normative device allowing comparisons of geographic information use across a broad range of decision-making.

It is expected that the modeling technique will be useful in gaining additional knowledge of the use of geographic information and analysis through empirical observation of current use. It is also expected that this additional knowledge of use will support one of the following:

- the identification of methods for establishing the value of information that will apply to the value of geographic information;

- the identification of necessary modifications to these evaluation methods;

- the determination that even more information is needed before we are able to determine the costs and benefits of geographic information use in decision making.

This chapter will first discuss the human decision-making process in general. Next, the specific characteristics that the modeling technique must be able to represent will be discussed. A discussion of the expected results from modeling will follow. The final section of this chapter will review and discuss available modeling techniques that may be suitable for this task.

2. The Decision-Making Process in General

The process of decision-making can be viewed as a working 'system'. The term 'system' derives from the systems approach literature (Churchman, 1968). It implies a multi-component, integrated process designed to achieve a specified set of goals. A system includes subsystems and their components, as well as the communication channels among these components for inputs, outputs, and feedbacks.

An example of the 'systems approach' to decision making is taken from (Quade, 1979), (Figure 2). The first step of the process is to formulate the goal of the decision to be made. The problem is clarified and specific objectives are identified. Criteria to measure the effectiveness of the decision made are also specified. In the search step, alternatives are designed, data is collected, and models of the alternatives are built, tested, and compared. The interpretation stage involves examining the alternatives for feasibility, evaluating the alternatives in respect to costs and effectiveness, interpreting results, and questioning the assumptions made in the prior steps. The verification stage allows for monitoring of the implemented alternative as well as other feedback. The verification stage also allows for the search of new alternatives.

A comparable view of decision making is taken from Simon (Newell and Simon, 1972). Simon depicts human decision making as a three-stage process (Figure 3), (Galliers, 1987). The first stage, intelligence, involves problem identification and data collection. Problem identification can be initiated by either problem detection or opportunity seeking. Data collection includes the collection, classification, processing, and presentation of the data necessary to prepare for later stages of the decision-making process, (Galliers, 1987).

The design stage involves the creation of alternative possible solutions. "The data gathered in the previous stage are now used by statistical and other models to forecast possible outcomes for each alternative," (Ahituv and Nuemann, 1987). Each alternative is evaluated in respect to such criteria as its technological and economical feasibility, its adherence to budget and time constraints, and its effects on the decision-making organization. The alternatives are then compared. If the available data is insufficient for this comparison, the decision maker may return to the intelligence stage.

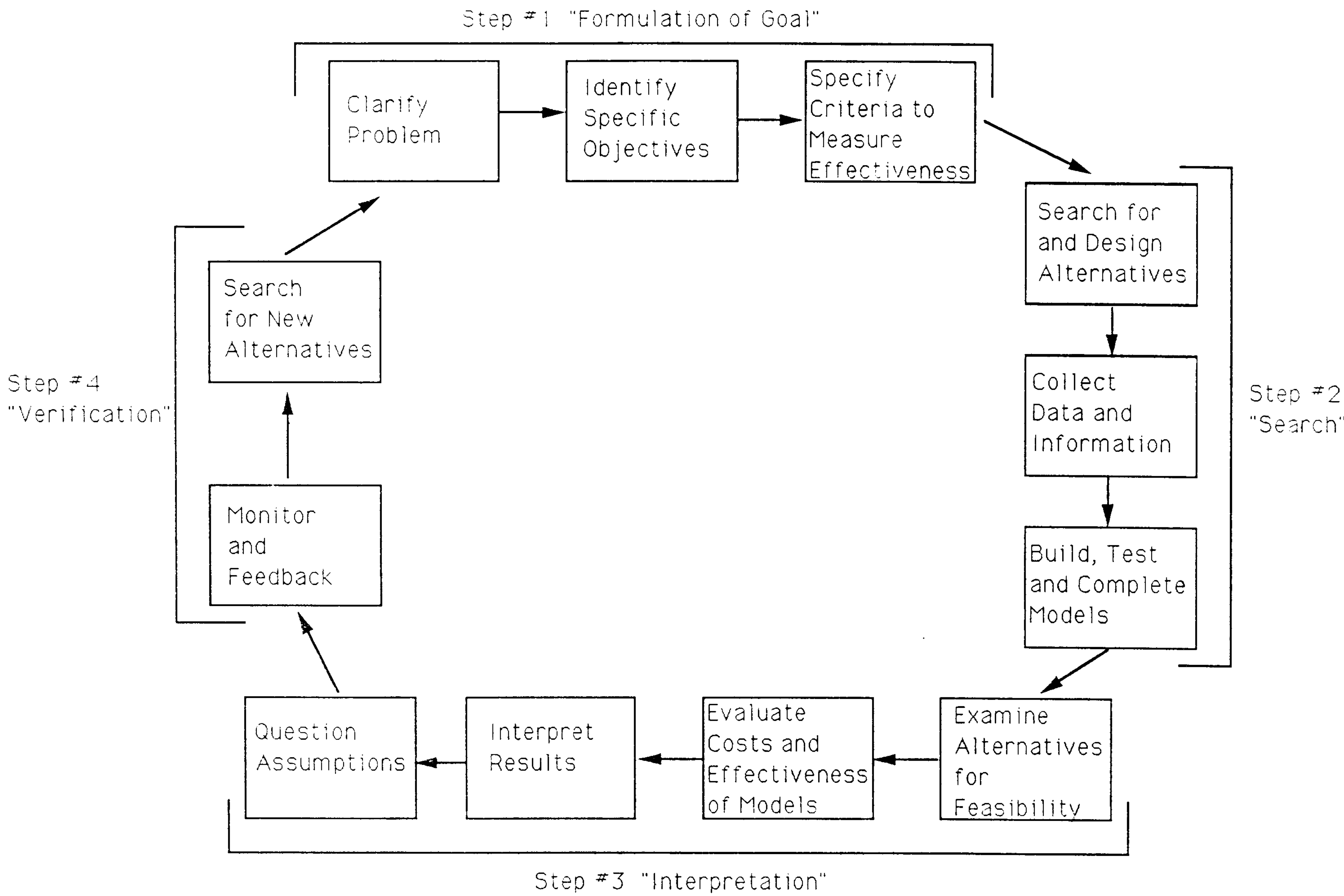


Figure 2. A Systems Approach to Decision Making (after Quade, 1979, p. 50)

During the choice stage, an alternative is chosen to be put into action. This decision must take into account such things as multiple criteria to be met, conflicting interests, uncertainty of alternative outcomes, and ability to implement the alternative. If no satisfactory solution is found, the decision maker may choose to return to the alternative generation stage.

Most models of decision-making follow a similar format as those described above: an initial step of problem identification, a search for alternative solutions, a comparison of these alternatives, and a choice of which alternative to be modeled. The more complete models identify some type of feedback and monitoring mechanisms also.

Information is an integral component in all of these procedures. It is used to ascertain the current situation, and to develop alternative solutions to meet the current situation's needs. Information is used to evaluate the alternatives with respect to decision criteria. Information is also used as feedback to the decision-making process. It is for these uses that information systems have been developed to support decision making.

3. Characteristics of the 'System' to be Modeled

Before the available modeling techniques are explored, it is important to discuss the characteristics of the ‚system', (i.e., the decision-making processes and supporting information system) that are to be represented in the model. To provide a robust model, it must be able to represent even the most complex decision-making processes. Characteristics exhibited in a complex process are described below.

Multiple Actors: All decision makers (and the flow of decisions and information between the various decision makers or groups of decision makers) and all other participants in the process and their relationships/duties must be explicitly represented in the model.

Alternative Paths: One or more sequences of steps support a process. A particular subset of steps can be defined as a 'path' through the process (Figure 4). Often, more than one path can be followed in a process. The modeling technique should be able to represent all possible paths through a process.

Conditional Choice of Paths: Where more than one path exists, decision criteria may direct which of the various paths will be followed (e.g., path A will be chosen if the value of X is less than five, path B will be chosen if the value of X is greater than five) (Figure 5). The technique should represent conditional choices and identify information necessary to make the decision.

Concurrency: In a process with multiple actors and multiple paths, concurrency is a possibility. The modeling technique should be able to differentiate between processes that occur simultaneously and processes that occur in sequence. It will also be necessary to represent resources that are common to two or more paths (e.g., a scarce resource such as time or money that could be exhausted by alternate paths acting concurrently).

Strict or Variable Precedence: In a sequence of events, certain steps cannot be performed until others have been fully or partially completed. At times, this precedence must be strictly adhered to (e. g., step B cannot begin until step A is complete). At other times, a variable precedence exists, (e. g., if condition X exists, step B can begin after step A is fifty percent complete; if condition Y exists, step B can begin after step A is thirty percent complete). The technique should be able to specify the necessary conditions for the various precedences to be enabled.

Feedback Paths: Geographic information use processes often include feedback or monitoring processes. Feedback loops, particular conditions that are being monitored, and threshold levels for these conditions that will invoke or inhibit action, need to be represented in the model.

Iterative Looping: A subset of steps of a decision-making process may need to be repeated numerous times. Iterations, nested iterations, and recursive sequences will need to be represented in the model.

Flow of Data, Information, and Objects: Understanding a process requires knowledge of the information and resources supporting it. Numerous entities, such as raw data, information transformed by certain steps, and information products used for subsequent decision making 'flow' through the process. These entities and the resources (time, money, inventory, etc.) being used or created by the process require representation.

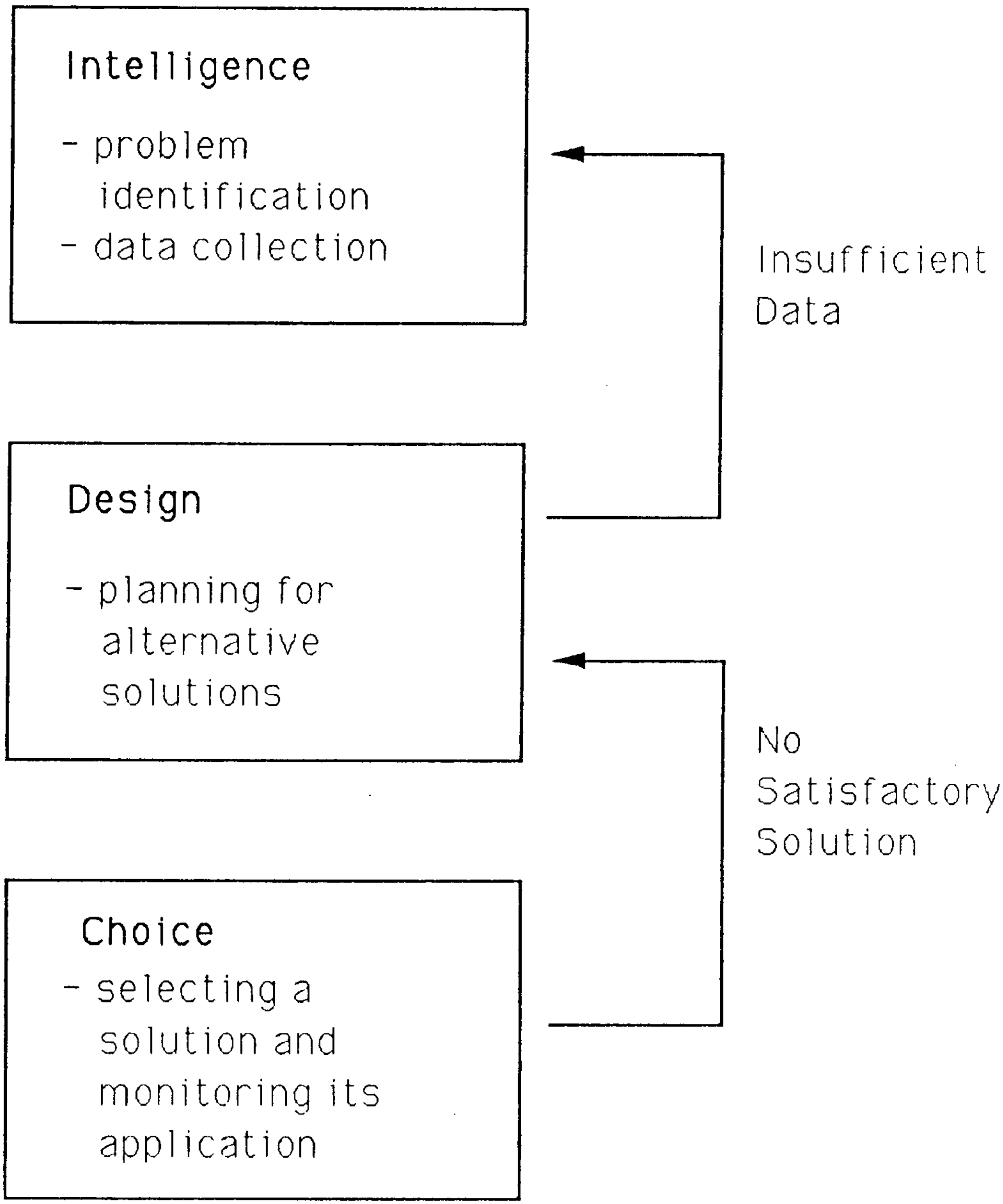


Figure 3. Simon's Model of Decision Making
(after Galliers, 1987, p. 20)

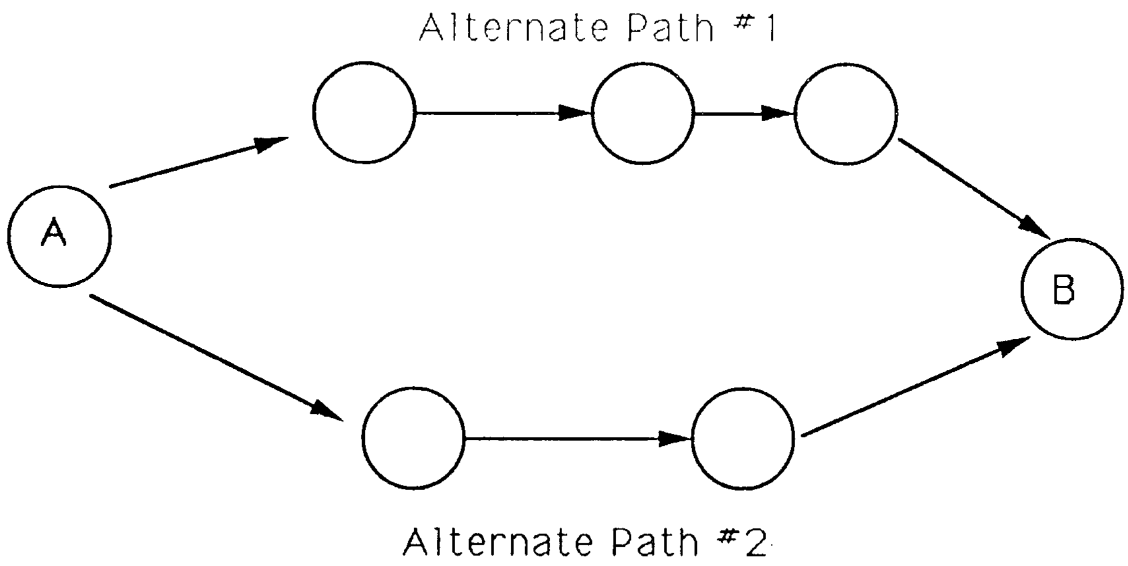


Figure 4. Alternative Paths from Step A to Step B

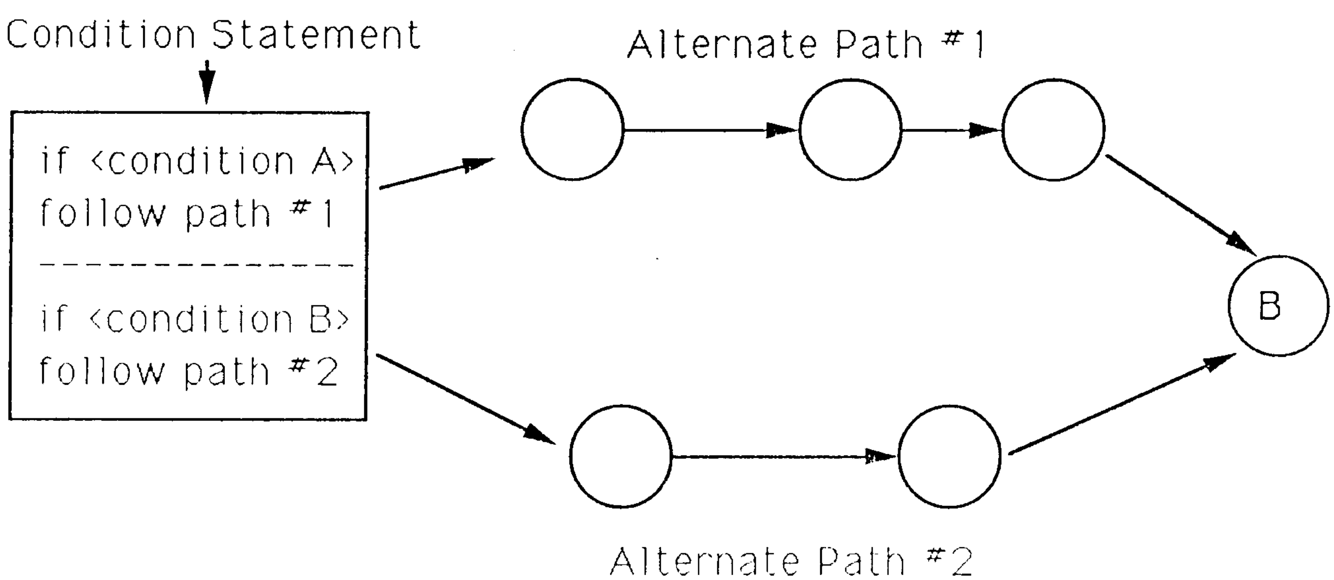


Figure 5. Conditional Choice

4. Expected Results from the Modeling Technique

The expected result will be a modeling technique, probably diagrammatic, and capable of modeling a decision-making process. The model will exhibit completeness, i.e., will represent all facets of the decision making. This will include representation of the process flows, data flows, and information flows throughout the decision-making process. The conditions which enable each stage of the process to occur will also be identified. The diagrammatical representation will lend itself to simulation of the decision-making process. To support the mathematical analysis of costs and benefits, variables regarding changes to the information will be carried along as the stages occur.

It is expected that the representation will reveal where geographic information is critical to the decision being made and what other types of information are associated with it. This should support measuring the relative 'share' that the geographic information and its analysis has in the overall decision-making task. This measure of relative impact will be translated into a relative sharing of the benefits once they are determined for the entire decision-making process. It should be noted that it will still be necessary Lo determine the benefits of the decision making outside this model.

5. Available Modeling Techniques

An accepted framework for modeling the use of geographic information and its analysis does not exist at this time. The objective of this research is to find a method suitable for such modeling. As discussed at the end of chapter 2, the method must be structured and systematic enough to be repeatable across case studies so findings can be compared. Concurrently, the Method will also provide enough detail of the use pattern to support establishing the value of the information.

A number of diagrammatical techniques are available for representations of systems. Some have already been used in the design of GIS databases and implementations. Most of the techniques come from the data processing and management science literature. A list of the most popular techniques and a brief description of each follows. Accompanying each description is a graphic example of the technique and how it represents the above characteristics. It must be stressed that the discussion of characteristics not represented by a specific technique is not meant as a criticism of that technique. Each technique has its own original purpose and advantages related to that purpose. If a person is creative enough, most of the above characteristics could be represented by each technique. This discussion is limited to those characteristics which can normally be represented by each technique.

Critical Path Method.

The Critical Path Method (CPM) is often used in the planning, scheduling, and control of projects. The overall project is divided into numerous activities. "Critical path methods involve a graphical portrayal of the interrelationships among the elements of a project, and an arithmetic procedure which identifies the relative importance of each element" (Moder and Phillips, 1964, p. 1).

A graph shows the precedence relationships, i.e., the dependencies of the program's activities leading to the end objective. The sequence of activities are represented as a network of arrows and nodes. There are two diagramming techniques: (1) activity on arrow (AOA) and (2) activity on node (AON).

The aim is to schedule the activities of the program and the use of scarce resources so that the cost and time required to complete the project are properly balanced. A network is created. 'Me critical path through a network is "the path with the least total slack." (Moder and Phillips, 1964, p. 61).

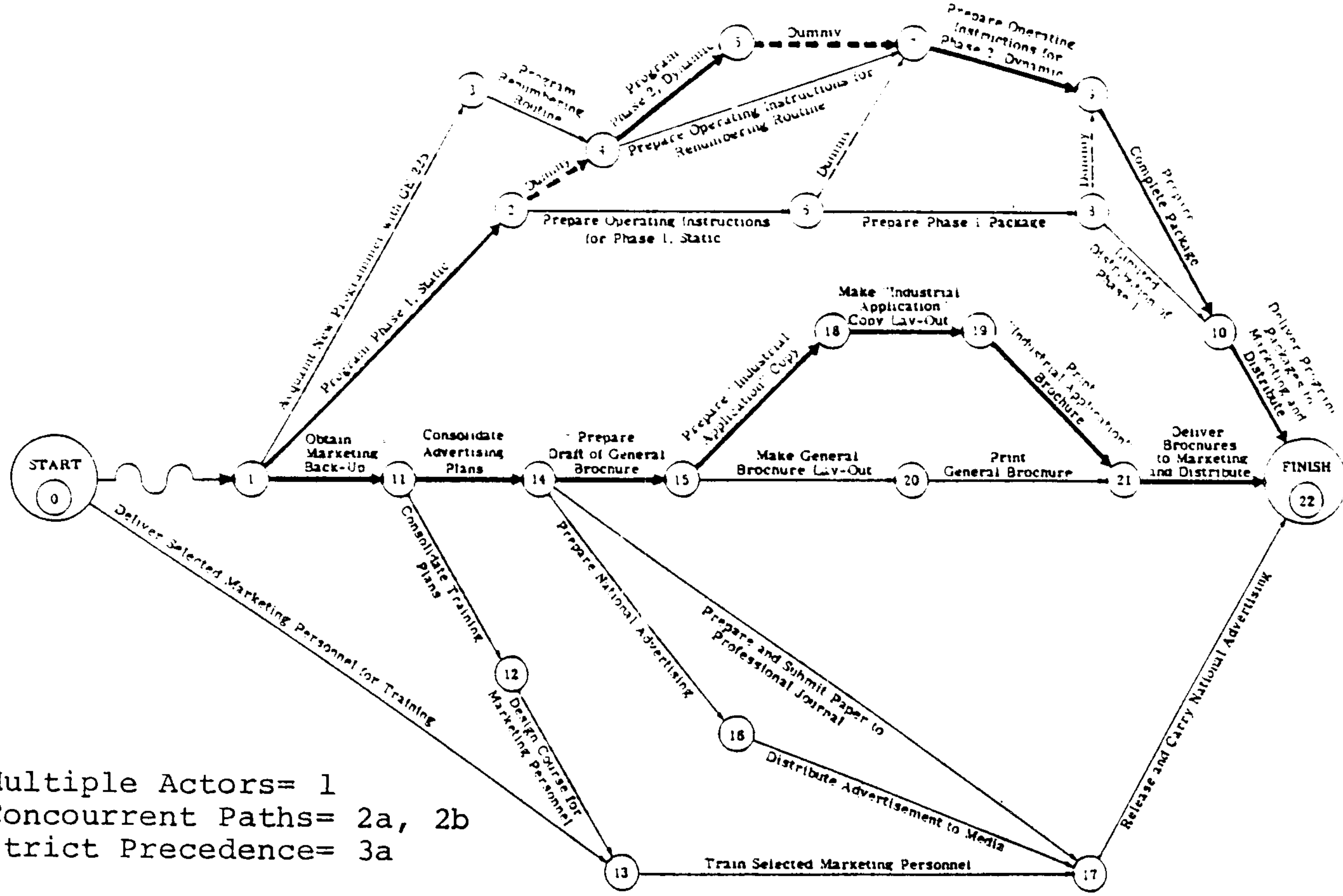
Figure 6 shows a CPM chart representing concurrency and strict precedence among the various paths. Multiple actors could be represented in the text that labels each line with its corresponding activity. Alternative paths between two events are not allowed in a CPM chart. Conditional choices are not represented in a CPM chart. Variable precedence can be represented only if activities are divided into sub-activities. Process flow in a CPM chart is one-directional, thus dis-allowing feedback and iterative loops. Flow of data and information is not shown in a CPM chart.

Similar to the critical path method, PERT charts are also based on a project network diagram (Moder and Phillips, 1964). PERT charts are a specific type of critical path method; the difference being that "PERT emphasizes the control of the time element of program performance and treats explicitly the uncertainty in the performance times Of the activities" (Moder and Phillips, 1964, p. 7). Three estimates of time are used in a PERT chart: a maximum, minimum, and modal estimate. The general critical path method uses only a single value to determine estimated start and finish times.

Data Flow Diagrams.

A data flow diagram shows the flow of data between various processing steps in a procedure. The processes to be carried out are included in the diagram, as are the stores of data that are created, accessed, and modified throughout the system (Wasserman, 1980).

A circle represents a process that transforms input data into output data. Data stores are represented by two parallel lines or by a rectangular box with one open end. Data flows are represented in text form along the arrows showing process flow, (Kowal, 1988). Although the symbology is slightly different, Figure 7 shows a data flow diagram representing concurrency, strict precedence, looping, data flows, and information flows. A data flow diagram does not generally show alternate paths and conditional choices. However, a representation was forced in Figure 7 (at point 6). This violates the rule that text added to the directional arcs represents only data flows. Another addition seen in Figure 7 is the use of square boxes to represent various actors.



Multiple Actors= 1
Concourrent Paths= 2a, 2b
Strict Precedence= 3a

Figure 6. CPM Chart (after Moder and Phillips, 1964, p.24)

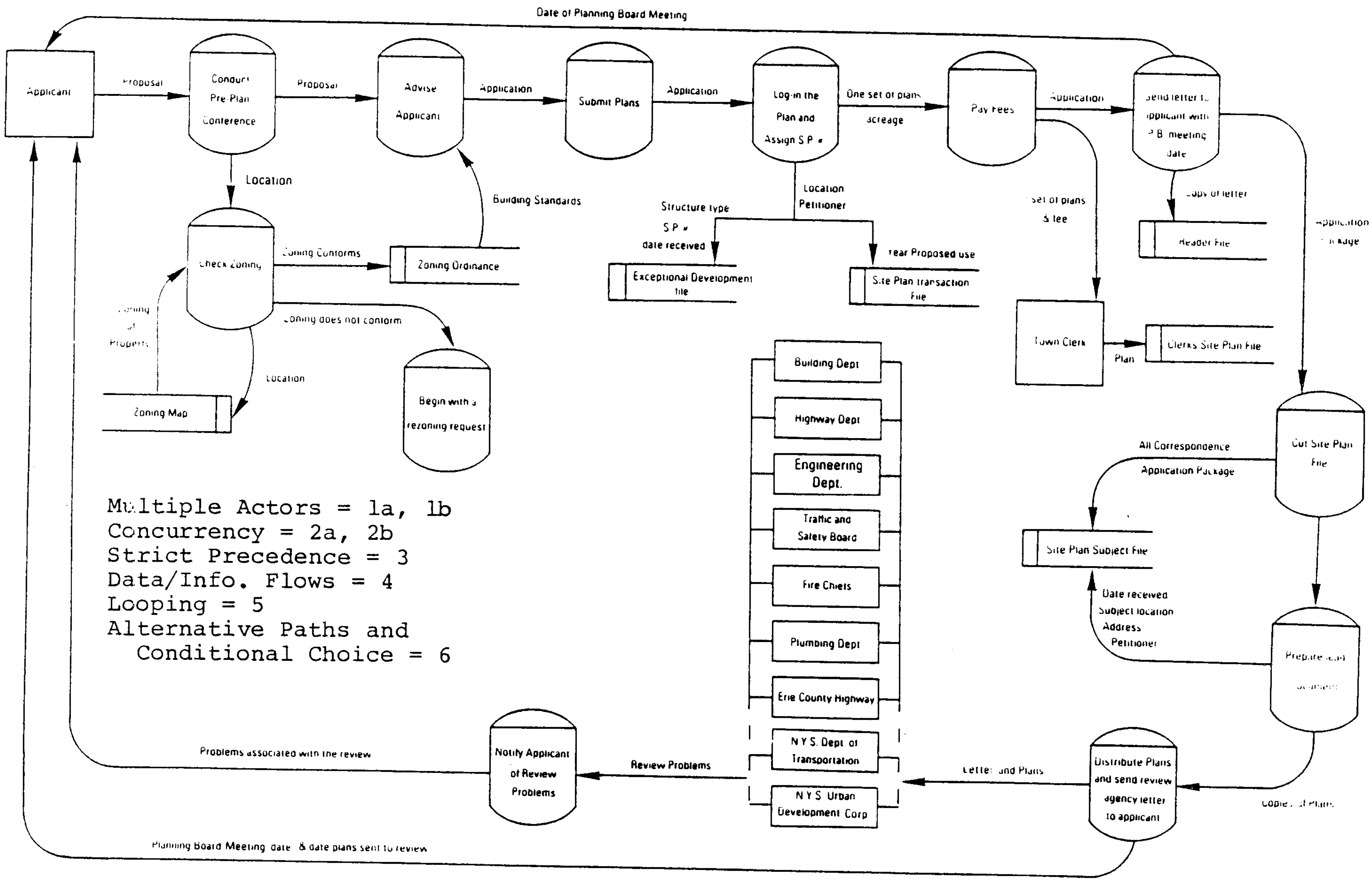


Figure 7. Data Flow Diagram: Site Plan Submittal Process (after Howard, 1984, p.

Decision Trees.

Decision trees are a graphical representation of sequential decision making conditions, (Stacey, 1983). Each condition is represented as a node, and all possible choices are represented by lines leaving that node. Only one line (path) is chosen. Figure 8 shows a decision tree which represents conditional choices and strict precedence. A decision tree does not show alternative paths that lead to the same decision, only alternate paths to different decisions. Neither actors nor data or information flows are specified on a decision tree. Concurrency is not allowed since a path choice must be made at each node. Variable precedence cannot be represented. Because of its linearity, a decision tree cannot represent feedback or iterative looping.

Entity-Relationship Diagrams.

An entity-relationship diagram (E-R diagram) is a graphic way of displaying the entity types, relationship types, and attributes of a data schema. (Chen, 1976). This tool is often used to model information requirements for database design. Rectangular boxes represent entity types, and diamond-shaped boxes represent relationships between entity types. Attributes of each entity type are represented by lines connected to the entity box, and the type of value associated with each attribute is represented by circles at the end of the "attribute" lines.

Although generally used to represent relationships between data entities, an extension of the E-R concept can be used to model processes by representing the actors and objects they act upon as entities, and representing the steps performed as relationships between these entities. Figure 9 shows an E-R diagram of this type. The combination of a rectangular box and a diamond-shaped box represents a relationship-converted entity type, (i.e., product is 'shipped' to customer, 'shipping' is performed by the clerk). A range of these conversions (or transformations) are discussed in the E-R literature, but do not always follow a single set of rules. It seems unlikely that an E-R diagram would prove useful in representing the procedural characteristics of a complex decision-making process.

Flow Charts.

A flow chart is a diagram that shows the step-by-step progression of a procedure. It is most often used in computer programming as an aid to algorithm design. A flow chart represents the 'flow' as a sequence of steps through the use of connecting lines and a set of conventional symbols. A box is used to indicate a processing step. A diamond represents a logical condition and arrows show the flow of control (Pressman, 1982).

In general, a flow chart does not show actors; one process controller is assumed. Alternative paths and conditional choices are represented by condition statements and branching paths. Since it is used to model computer programs, concurrency of multiple paths is allowed only if parallel processors are available. Strict precedence is represented by the arrows, but variable precedence is not available. Feedback paths are not easily represented unless they are forced into the form of an iterative loop. Flow of data, information, and decisions is not generally seen on a flow chart. Figure 10 shows a flow chart representing these characteristics.

Markov Chains.

A markov chain is a method which represents the probability of one event occurring after another (Kemeny, et. al., 1966). Nodes are used to represent events. The connecting arc between two events is labeled with the probability that the second event will occur after the first. The markov chain in Figure I I shows that the probability of event E4 occurring after event El is .60 while the probability of event E2 occurring after event El is only .40. Event E3 will definitely occur after E2 (probability of 1.0). There is a probability of .10 that E3 will repeat itself, and a probability of .90 that event El will be the next to occur. The markovian technique assumes that the probability of an event occurring is dependent upon only the decision made at the previous node (Wagner, 1975). Figure 12 shows a markov chain showing strict precedence, alternate paths, conditional choice, and looping. Concurrency, variable precedence and feedback are not represented in a markov chain. Multiple actors, data flow, and information flow also cannot be represented with a markov chain.

While any one of the above mentioned techniques meet one or more of the necessary requirements for modeling a complex decision-making task, none completely fulfill the need. The matrix in Figure 13 shows which characteristics of a decision-making process can be represented by each of the discussed modeling techniques. (A paper which includes a more extensive examination of modeling techniques and additional criteria is being prepared by Dickinson and Benwell. This paper (in draft form) is included in Appendix A.) The author concludes that these available techniques are not able to represent the entire set of characteristics of the decision-making system to be modeled for the purpose of this research. This is not a criticism of the above mentioned techniques, since none of these tools were developed for use in modeling decision-making processes. However, a technique to be used in observing the various uses of geographic information and analysis needs to be able to represent as many of the characteristics of complex decision making as possible. A technique found in the computer science literature, termed petri nets, does show potential for application to most, if not all of these characteristics. Since petri nets seem more likely to meet the needs of modeling

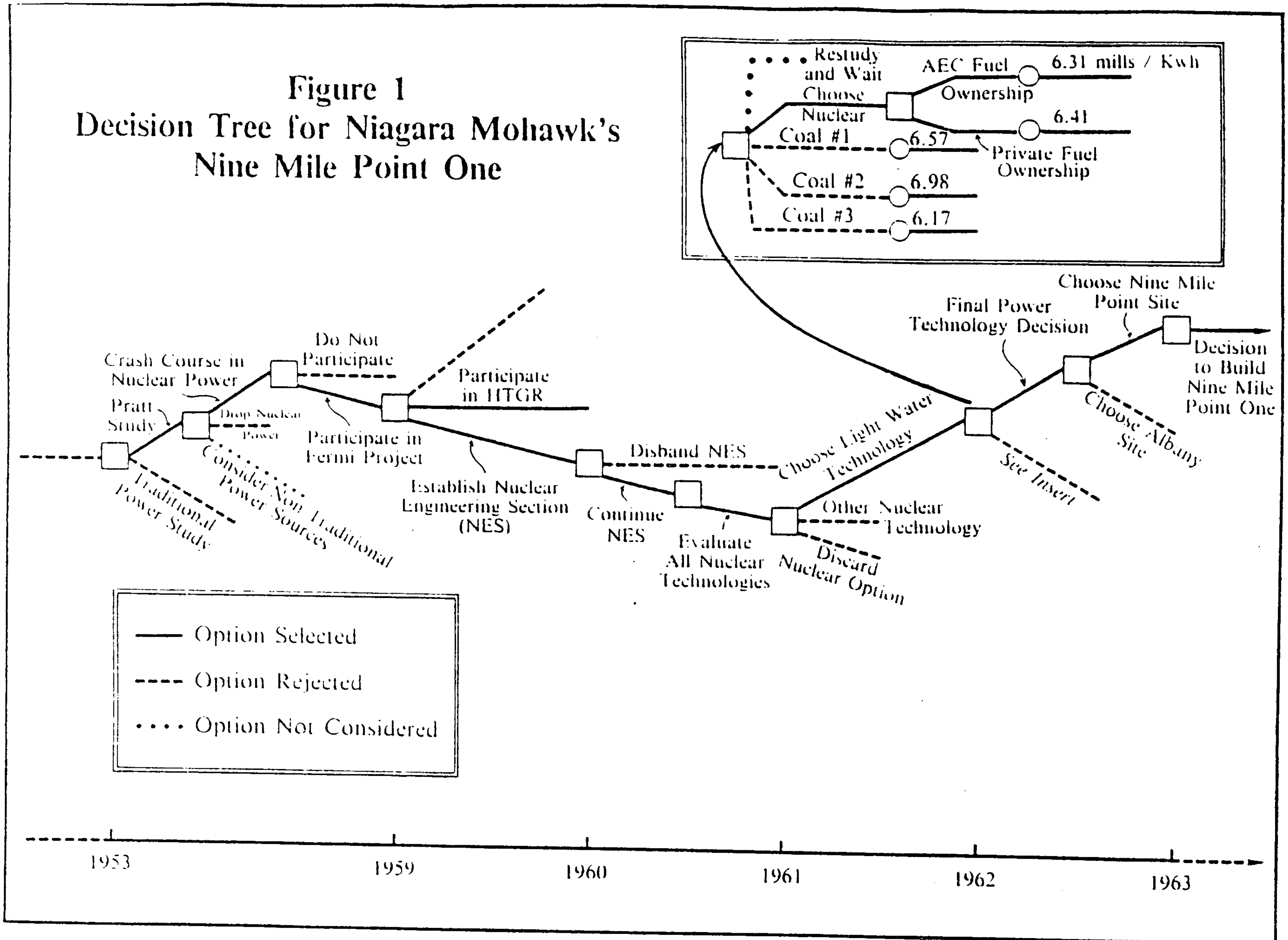


Figure 8. Decision Tree: Decision to Build Nuclear Power Plant (after Stacey, 1983, p. 4)

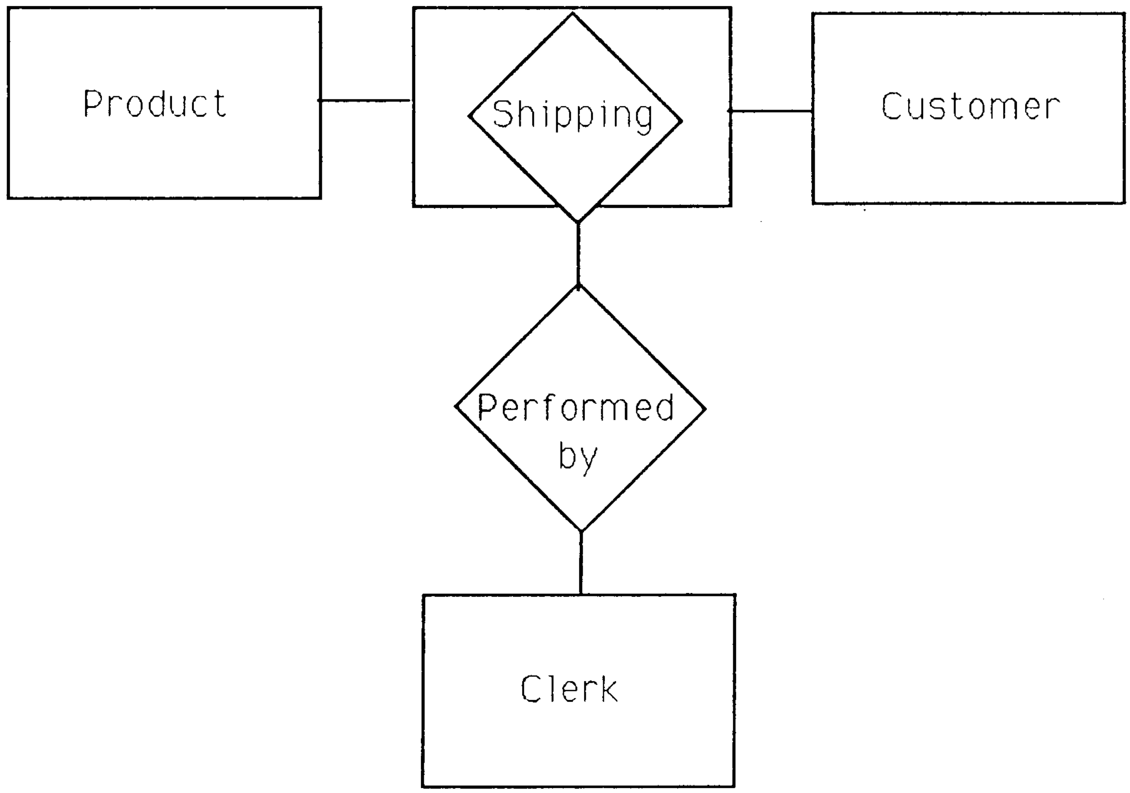
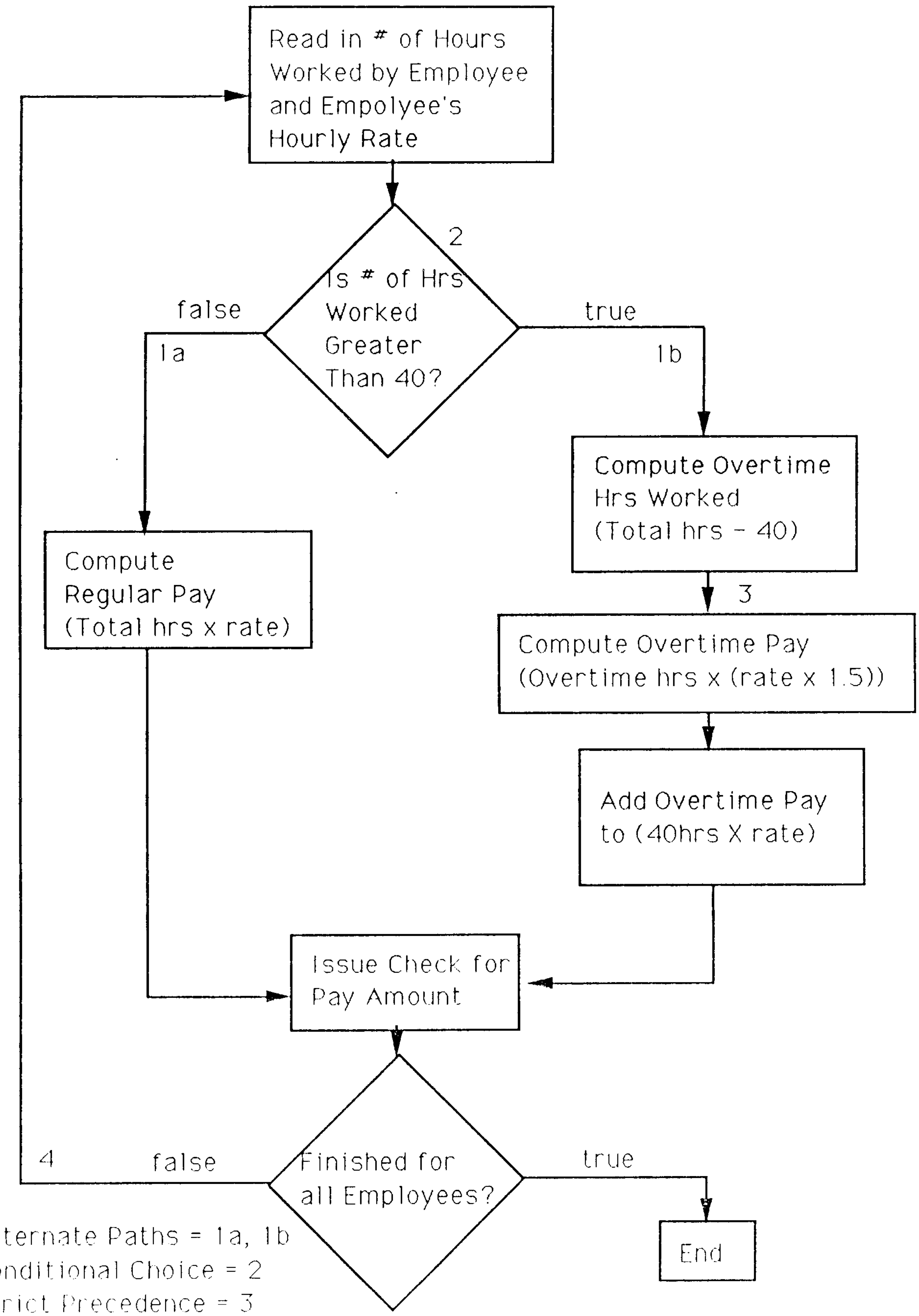


Figure 9. E-R Diagram (Chen, 1983, p.136)



Alternate Paths = 1a, 1b
Conditional Choice = 2
Strict Precedence = 3
Iterative Looping = 4

Figure 10. Flow Chart: Algorithm to Compute Employees' Pay

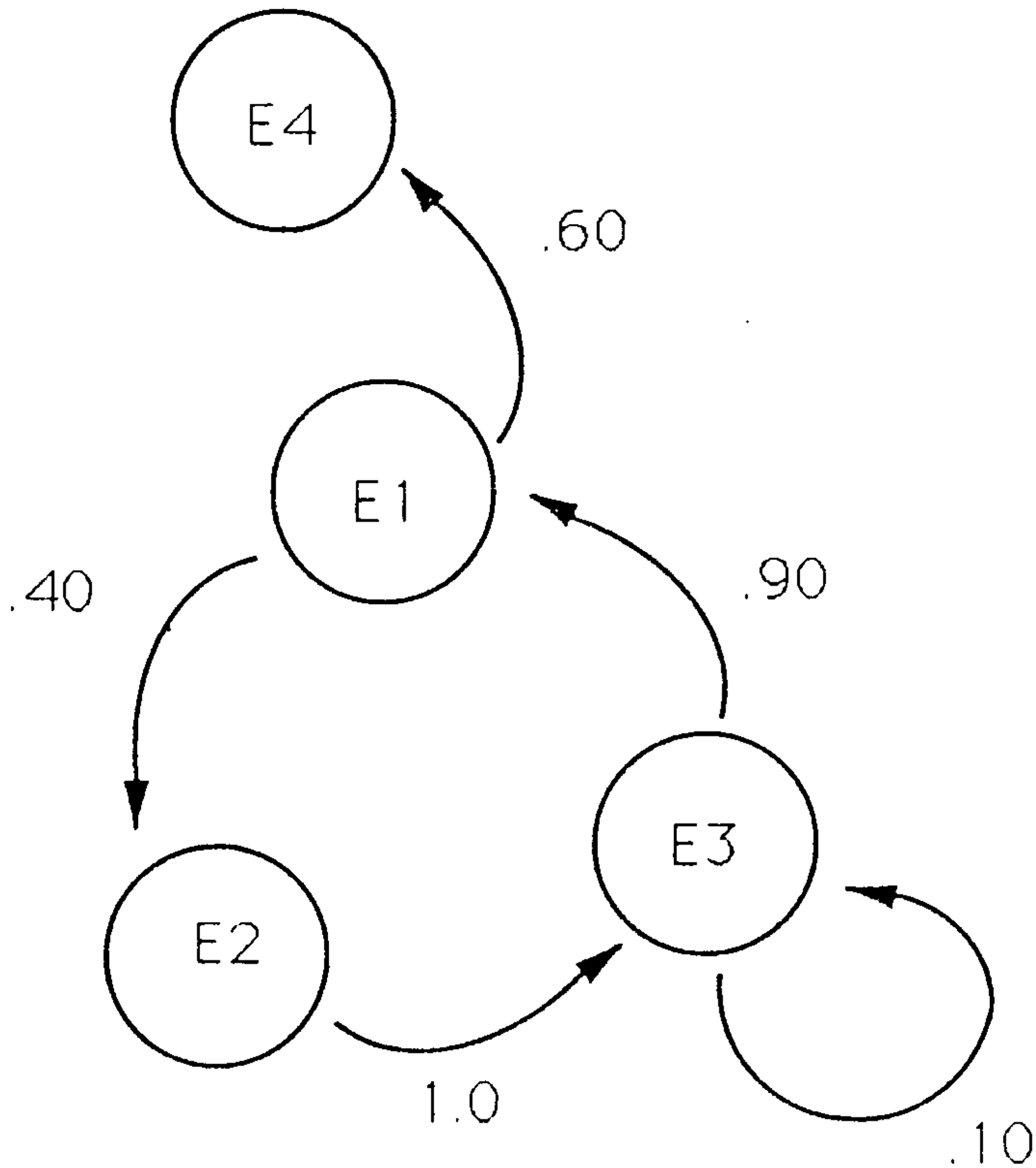


Figure 11. Markov Chain

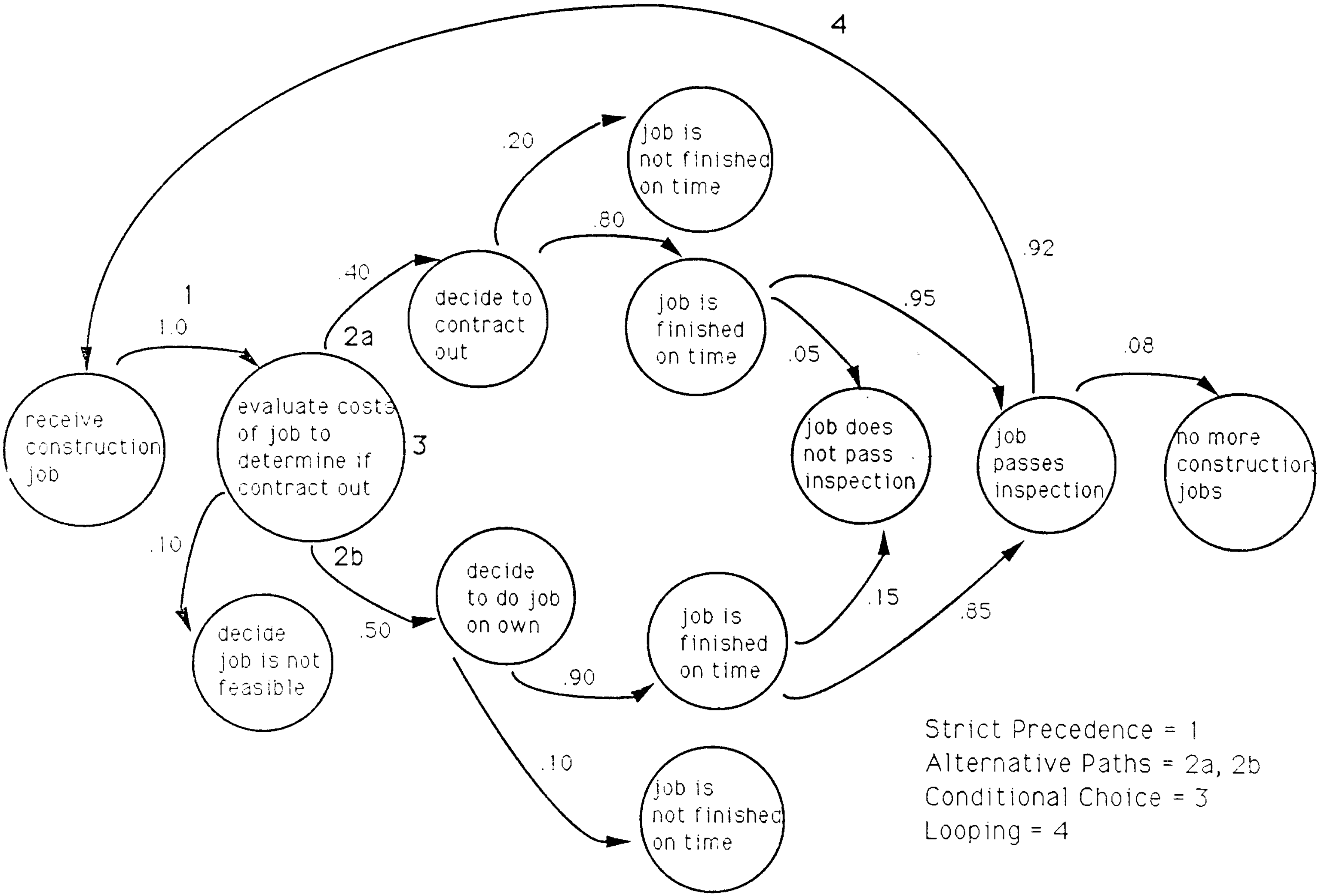


Figure 12. Markov Chain: Contracting Jobs

Decision-Making Characteristics to be Represented ↓ / Available Modeling Techniques →	CPM & PERT	Data Flow Diag.	Dec. Tree	E-R Diag.	Flow Chart	Markov Chain	Petri Nets
Multiple Actors	X			X			X
Alternative Paths			X		X	X	X
Conditional Choice			X		X	X	X
Concurrency	X	X					X
Strict Precedence	X	X	X		X	X	X
Variable Precedence							
Feedback/Monitoring							X
Iterative Looping		X			X	X	X
Flow of Data/Info.		X		X			X

Figure 13. Available Modeling Techniques vs. Characteristics to be Modeled

decision-making, they have been chosen as the modeling technique for this research task. The next section will describe petri nets in detail, and explain why they have been chosen. Chapter 4 will illustrate the application of petri nets to the case study selected for this research.

6. Petri Nets

Petri nets are a scientific and mathematical tool developed for studying systems and processes (Symons, 1962). They were originally developed by C. A. Petri in 1962 to help him describe and analyze the asynchronous components of a computer system (Petri, 1962). The petri net theory was developed as an extension of net theory. (Net theory uses a series of links and nodes to represent complex systems, with particular attention paid to the precedence-relationships between components). In 1968, the symbology of petri nets was formalized by A. W. Holt and others at the Information System Theory Project of Applied Data Research, Inc. 'Me final report of that project showed how petri nets could be used to model and analyze parallel, asynchronous, and concurrent components in computer systems (Holt, et. a], 1968).

Petri nets can be used as an auxiliary analysis tool, whereby a system is modeled as a net and the net is analyzed. The model is modified to correct for any shortfalls, and the system may then, via the petri nets, be analyzed and understood. Petri nets can also be used in the design and specification of a process, (such as a decision-making task). A petri net represents a system in terms of events (or activities) that occur in the system, a set of conditions or states (which may hold true or not true), and the relationships between the two (Peterson, 1981 and Reisig, 1982). The basic form of a petri net represents a real world 'system' in the following manner:

Petri Net Component	Real World System
place	specific condition of the system
transition	specific event or activity
arc	relationship between conditions and events
input to a transition	conditions that must exist for the event to occur
output of a transition	changes to the system due to the occurrence of an event
firing of a transition	occurrence of an event
token in a place	a specific condition which holds true
marking of a net	specific state of conditions in system

Circles are used to represent places, rectangular boxes or bars are used to represent transitions, arrows represent the input and output relationships between the places and transitions, a small black dot inside a circle represents a token in that place, and the distribution of tokens across a net represents the marking of that net.

7. Petri Net Example

Figure 14 is a petri net representation of a retail order event. There are two actors in the system, the customer and the vendor. C1 represents the condition that the customer is ready to choose whether or not to order. The dot inside the circle is a token, which represents that this condition holds true. The current marking of this petri net is (C1, VI) since these two places contain tokens. Since condition C1 holds true, both events El and E2 are enabled (i.e., can occur). A transition is said to be enabled if tokens exist in all input places (i.e., if all required conditions hold true). Specific firing rules for events El and E2 can be used to determine which event actually occurs.

Figure 15 shows the resulting marking of the petri net if event El (customer chooses to order) occurs. When El occurred, the enabling token from C1 was removed and put into the output place, C2 (customer has decided to order). At this time, E3 (the placing of an order) becomes enabled since there are tokens in both its enabling conditions, C2 (customer has decided to order) and VI (vendor is ready to order). When event E3 fires, the tokens will be removed from conditions C2 and V I, and placed in conditions C4 (customer has ordered) and V2 (vendor has taken order). It is through the firing of transitions and moving of tokens that a petri net can be used to simulate the actual processes of the system being modeled.

The relationships between the conditions and events can be shown in matrix form. (The reason for representation in matrix form will be explained in the petri net analysis section). An input into an event is denoted by a -1, and an output from an event is denoted by a +1. Figure 16 shows the matrix for the petri net in Figures 14 and 15. For example, the matrix row labeled E3, shows that E3 (the placing of an order) requires an input token from C2 (customer has decided to order) and an input token from V I (vendor is ready to order). That same row of the matrix shows that upon firing, E3 will output one token to C4 (customer has ordered) and one token to V2 (vendor has taken order).

8. High-Level Petri Nets

There have been many extensions and modifications to the basic form of petri nets. One such extension, called a colored petri net, makes them much more suitable to the modeling of information-use systems (Jensen, 1987). In a colored petri net, the tokens no longer represent just whether a condition holds true or not true. Instead, the tokens represent objects or information that flow through the system. Different types of tokens are allowed in the same petri net. (The term "color" refers to the "type" of token, not its actual color.) Each event in the petri net has both an enabling condition and a firing rule for every token color in the net. Figure 17 shows a petri net model of an operating system's disk scheduling algorithm (Peterson, 1980). In this petri net, conditions are represented by circles and labeled as places (Pi). Events are represented as rectangles and labeled as transitions (Ti). This will be the symbology followed for the remainder of this document. Following is the legend for places and transitions:

P1 = request for disk space waiting
P2 = disk has been allocated
P3 = channel has been allocated
P4 = processing is complete
P5 = disk and channel have been released
P6 = disk drives are available
P7 = channels are available

TI = request disk space
T2 = allocate disk
T3 = allocate channel
T4 = process the program
T5 = release disk and channel
T6 = stop processing

In a colored petri net, each transition has its own input/output matrix, (as compared to one input/output matrix for a regular petri net). In Figure 17, the matrices for each transition are placed directly above the transition symbol. Each matrix shows the firing rules for that particular transition. The matrix is divided by a solid line. On the left side of each matrix are the possible combinations of input tokens; on the right are the corresponding combination of output tokens.

For example, when event T2 (allocate disk) fires, it expects one token from PI (i.e., a request for disk space is waiting). Since this is a boolean condition, there is no colored token in Pl. Therefore, only a black dot exists in the PI column of the matrix for T2. Event T2 also expects a token from P6. This is a colored token and will either be a 1, 2, or 3. 'Me P6 column in the matrix lists each possible token type. If the token from P6 is a 2, the output of T2 will be a 2 put in P2. This is shown by the second row of the matrix.

Now that T2 has fired and placed a token in P2, T3 has become enabled. (A token already existed in P7 which is the other input place to T3). As event T3 fires, the inputs are taken from P7 (channels available) and P2 (disk drive allocated). The matrix for T3 shows that the possible inputs from P7 are A or B, and the possible inputs from P2 are 1, 2, or 3. Notice that the matrix must provide for all possible combinations of input tokens. For example, the specific combination of channel A and disk 2 creates an output token of K to P3 (shown by the second row of the matrix). Event T4 takes the input from P3 and outputs the same token to P4 (shown by the second row in the T4 matrix). Event T5 takes the input from P4 and creates three new tokens (an A for P7, a 2 for P6, and a non-colored token for P5).

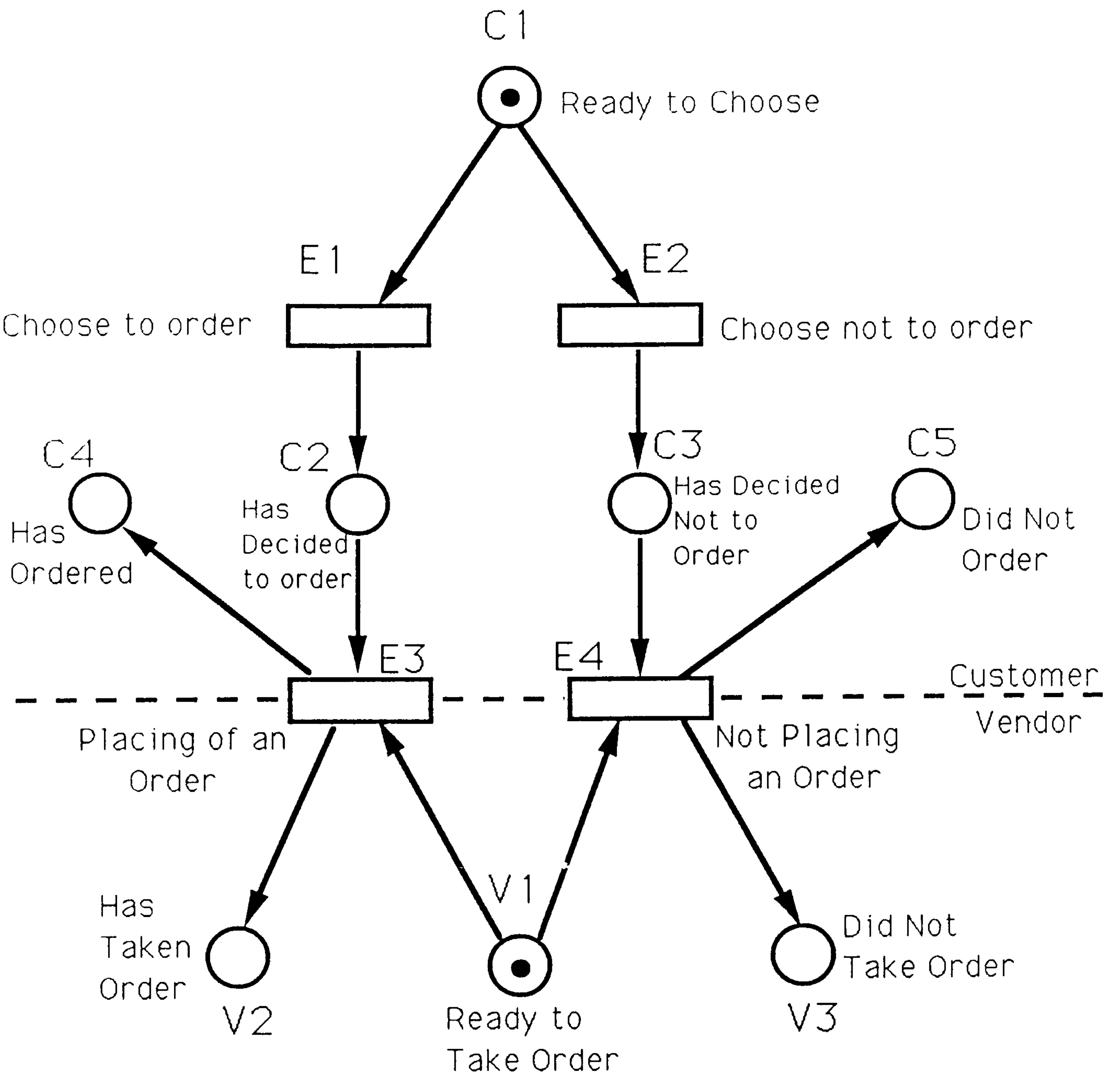


Figure 14. Petri Net: Retail Order Event-Initial State (after Meldman, 1977, p.38)

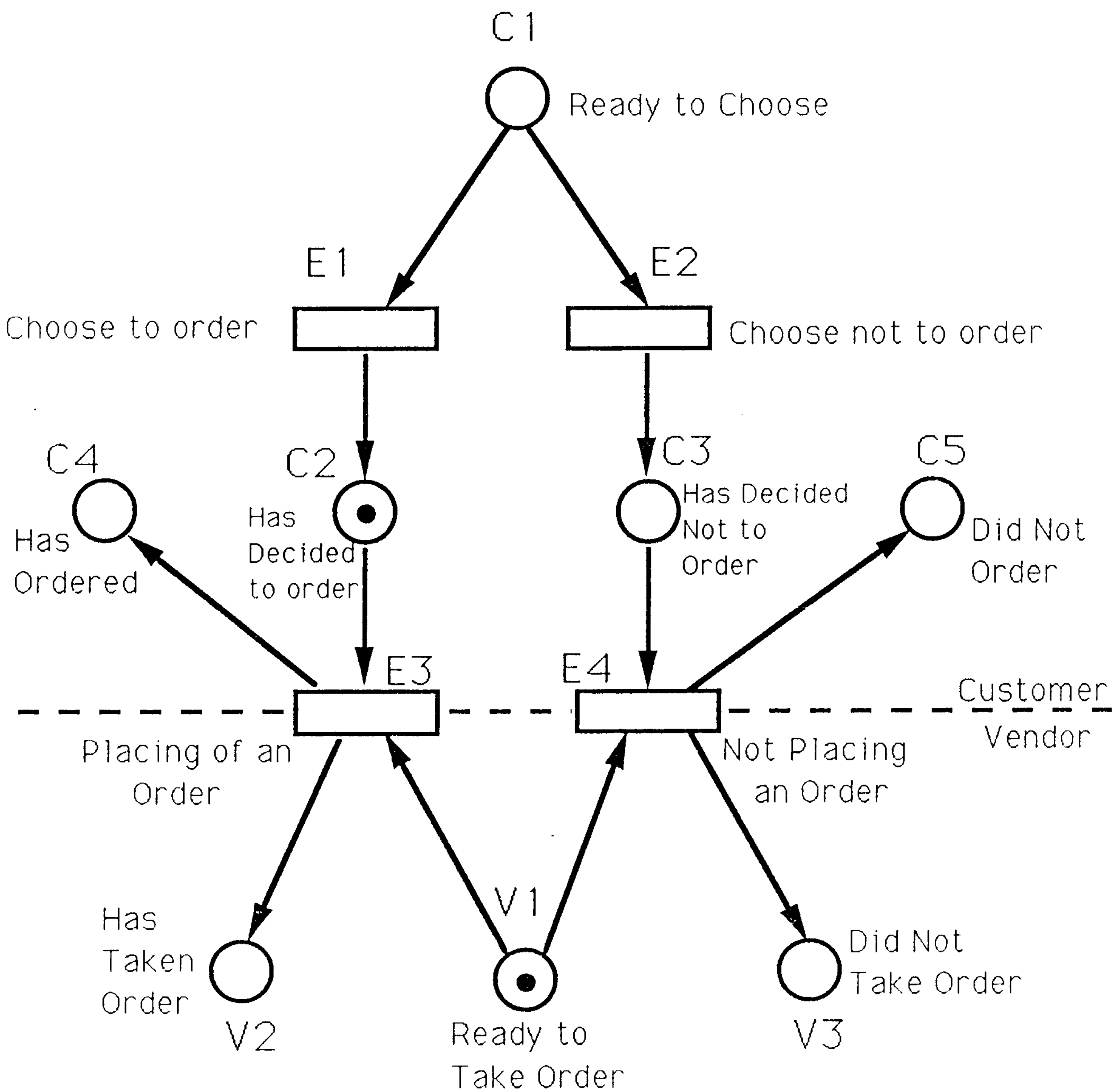


Figure 15. Petri Net: Retail Order Event-After E1 "Fires"
(after Meldman, 1977, p.38)

	C1	C2	C3	C4	C5	V1	V2	V3
E1	-1	1						
E2	-1		1					
E3		-1		1		-1	1	
E4			-1		1	-1		1

-1 = Input to an Event
1 = Ouput from an Event

Figure 16. Petri Net Matrix: Retail Order Event

T1

out
P1
•

T2

in		out
P1	P6	P2
•	1	1
•	2	2
•	3	3

T3

in		out
P7	P2	P3
A	1	J
A	2	K
A	3	L
B	1	M
B	2	N
B	3	P

T4

in	out
P3	P4
J	J
K	K
L	L
M	M
N	N
P	P

T5

in	out		
P4	P7	P6	P5
J	A	1	•
K	A	2	•
L	A	3	•
M	B	1	•
N	B	2	•
P	B	3	•

T6

in
P5
•

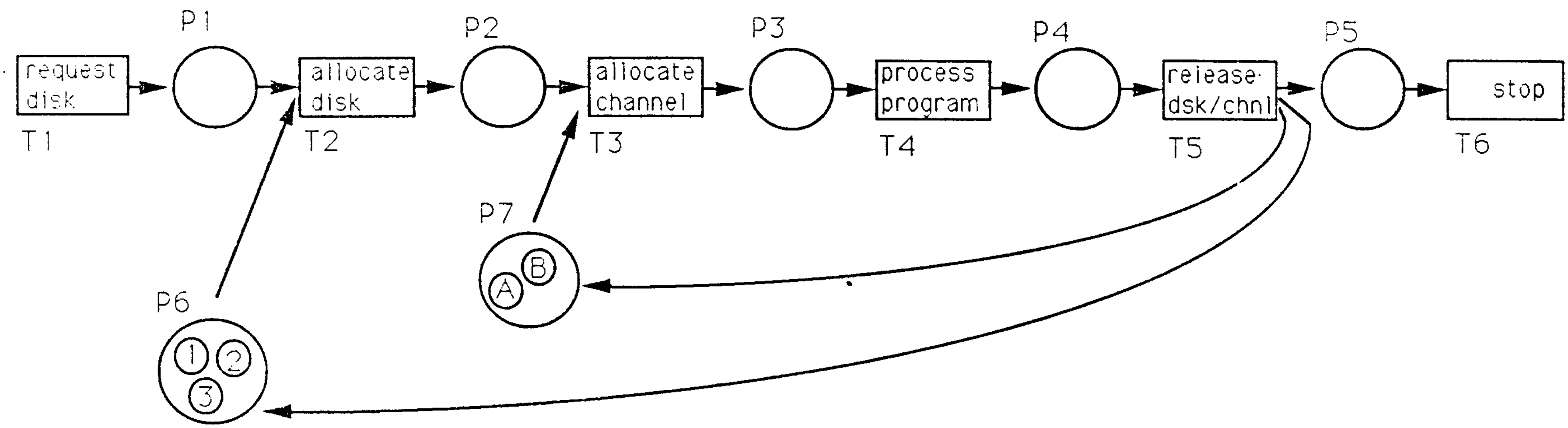


Figure 17. Colored Petri Net: Disk Scheduling Process (after Peterson, 1980, p.41)

9. Petri Net Analysis

Petri nets are represented in matrix form to support the analysis of the modeled system. Analysis is generally performed to check for desired properties in the petri net such as safeness, boundedness, conservation, liveness, reachability and coverability. Firing sequences and equivalence and subset problems can also be determined with analysis.

Safeness is an important property for hardware devices. "A place in the petri is safe if the number of tokens in that place never exceeds one" (Peterson, 1981, p. 80). The more general case of safeness is that of k-boundedness. This property only requ ires that the number of tokens in a place cannot exceed the integer k.

A third property analyzed in petri nets is conservation. Strict conservation requires that the total number of tokens in the net remains constant. However, since tokens can represent various resources and transitions may transform one type of token (one type of resource) into multiple tokens, a weighting factor must be applied to the various tokens. This is a very important property when analyzing resource allocation in a computer operating system.

Liveness is the complement to deadlock. "A deadlock in a petri net is a transition (or set of transitions) which cannot fire" (Peterson, 1981, p. 85). This does not require a transition to be enabled, only that it has the potential to be enabled. This property is important in resource allocation for a computer system.

"The reachability problem is perhaps the most basic petri net analysis problem" (Peterson, 1981, pp. 87-88). This analysis questions if a particular marking (i.e., particular state of conditions holding true) is possible. Coverability is very similar to reachability, but involves more markings.

Another type of analysis involves determining the firing sequences of the petri net's transitions, and specifically, if particular sequences are possible. An example of an equivalence or subset problem involves showing "that two different marked petri nets with the same number of transitions (but perhaps different numbers of places) will generate the same sequence of transition firings (Peterson, 1981, p. 90).

It certainly seems that many of these properties would be useful in analyzing decision-making systems. The safeness, boundedness, and conservation properties could aid in the analysis of resource allocation in a system. Liveness could be used to pinpoint areas of deadlocks, or perhaps bottlenecks, in the processing steps. These type of properties would be useful in the design of more effective decision-making systems. Firing sequence information would provide answers to what activities could be expected given a particular set of conditions. The equivalence properties would be extremely useful in comparing various petri nets from different studies. (A more in-depth explanation of the analytical properties of petri nets can be found in Benwell and Dickinson, 1990. A draft of this paper is included in Appendix B.)

The actual steps involved in these types of analyses are beyond the scope of this research. The first objective is to show that it is possible to create a petri net model of geographic information use in decision making. The next task is to show how measures of costs and benefits of information use could be attached to the model. If these two steps are successful, then analysis will be the next step. Commercial software is available for analysis of the basic petri net model in the range of a few thousand dollars. However, software for analysis of higher-level petri nets has become available just recently and is selling for over twenty thousand dollars.

10. Why Petri Nets have been Chosen

The properties and characteristics of petri nets are such that they are well-suited to the representation and analysis of the flow of control and information in systems, especially those which are composed of communication sub-systems that operate asynchronously and concurrently. Petri nets are able to represent numerous decision-making system components in one model. They are able to model dependent and independent concurrency among components, conditional decision points, feedback and iterative looping, and static and dynamic components of a system (Peterson, 1981).

Petri net representations of many of the decision-making characteristics discussed earlier in this chapter can be seen in Figures 14 and 17. In Figure 14, C1 shows a conditional choice. Either El or E2 will occur, but not both. If El fires, the token is removed from C1, thus disabling E2. Condition C2 could act as a monitoring condition, (i.e., is there a customer ready to order?). Multiple actors are shown by dividing the petri net into the various actor roles (customer and vendor). Figure 17 shows strict precedence, looping, and information flow (i.e., which disks and channels are being used). Figure IS is a petri net showing the concurrency of a surgeon and a patient preparing for surgery. Figure 19 is a possible extension to Figure 14 and shows alternate paths leading to the shipment of an order.

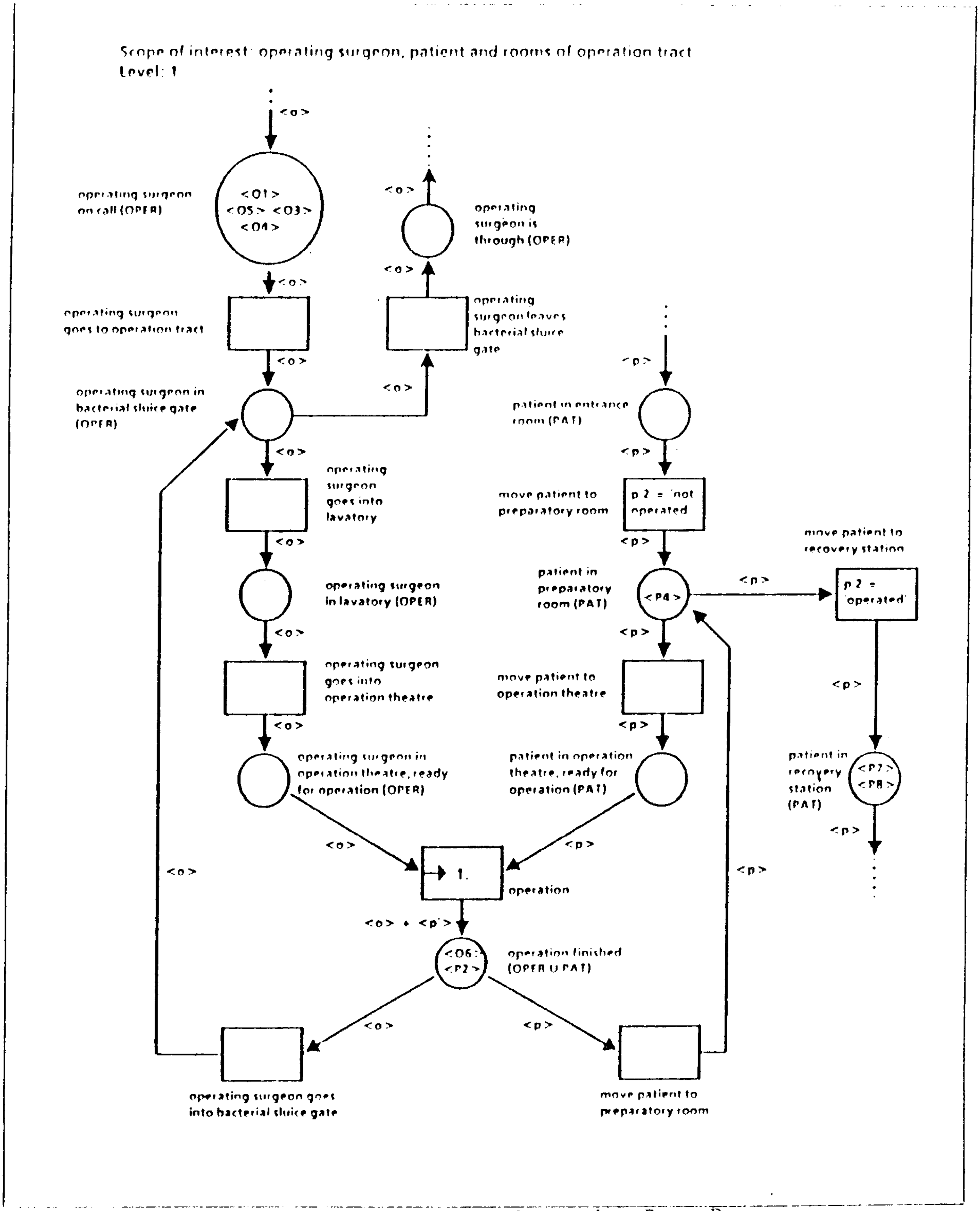


Figure 18. Petri Net: Pre-Operation Room Process
(Rothemund, 1986, p. 97)

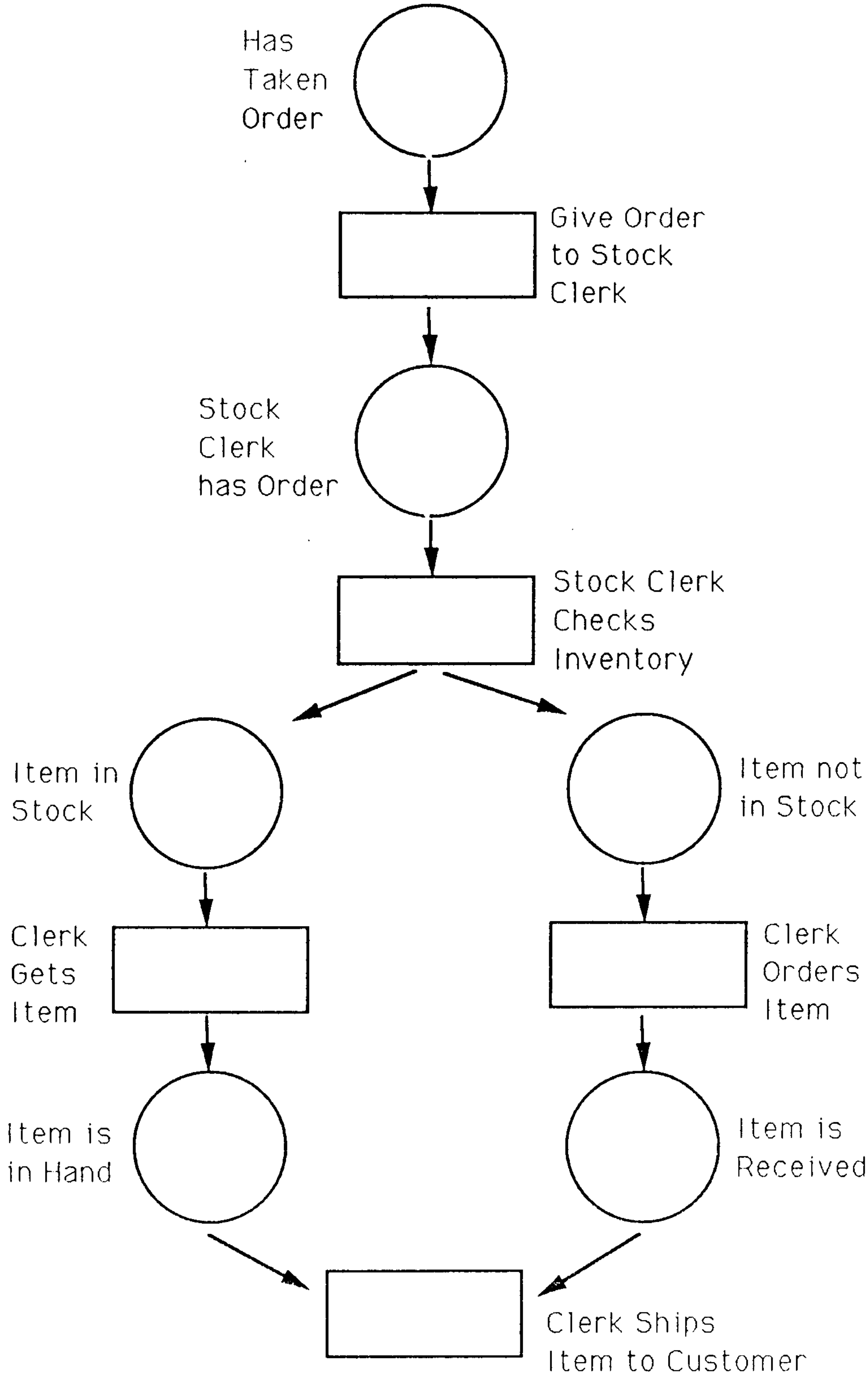


Figure 19. Petri Net: Filling an Order

Other characteristics add to the applicability of petri nets to this research task. Petri nets are able to represent systems at different levels of abstraction. Colored petri nets enable different types of information to be attached to different tokens that can be traced through the system. A petri net can be represented in both graphical form and mathematical form (matrix algebra). As discussed earlier, they can be analyzed for such properties as safeness, boundedness, conservation, liveness, and reachability (Peterson, 198 1). Petri nets can be used to simulate the activities and different states of the system. This modeling technique will produce a very structured representation of a decision-making system, including simulation of the flow of information and resources through the process. Petri nets are currently being used in New Zealand for modeling land information system applications (Benwell, 1990). Literature has also been found showing petri net modeling of information systems in the business, law, and medical fields (Lausen, 1988, Meldman and Holt, 1971, Peimann, 1988).

Once a petri net representation of a real-world decision-making system is constructed, it is expected that it will be possible to attach a function to each transition. The functions would be positive or negative effects on measures (colored tokens) such as costs in dollars, benefits in dollars, benefits in person hours saved, expenditure of person hours, etc.). The actual modifications made to the petri net technique will not be established until more information on the specific uses, costs, and benefits is collected. Chapter 4 will discuss the information collected at a specific case study site on particular decision-making processes, and the costs and benefits associated with the use of geographic information in these decisions.

Chapter 4 - Application of Petri Nets to Specific Geographic Decisions

1. Introduction to the Methodology

In Chapter 2, a need was established for a structured modeling technique to represent the use of geographic information and analysis in decision making. The technique is expected to support observation and understanding of "use" which in turn is expected to support establishing the "value" of such information. Chapter 3 discussed the available modeling techniques, and petri nets were chosen for their ability to represent more of the desired characteristics than any other technique. The remaining portions of the research objectives are:

- to test the chosen modeling technique for completeness and validity in a specific instance, and

- to identify measures of costs and benefits that can be attached to the components of the model.

It must be stressed that this research is extremely exploratory in nature. The methodology does not involve the creation of a hypothesis, followed by data collection, inference from the sample data set, and conclusions. Instead, the methodology for this research is empirical observation followed by hypothetical conclusions and predictive generalizations. It is expected that this research will serve as an experimental prototype for further research. It is realized that "value" is subjective and therefore, no explicit generalization of value figures will be produced by this research. Because of its subjectivity, the "value" of geographic information and its analysis in decision making is a topic which has not received a great deal of research. This has led to an unmet need for some type of procedure to support the documentation of "use" of geographic information in decision making. At the very least, documenting the "use" will offer a structured framework for describing "value." However, this researcher feels that through iterative research of the "use" and "value" questions, a more structured prescription for assessing value will be documented.

The basis of this research focused on the systems analysis methodology, supported by a non-structured interview process. Systems analysis involved the identification of the goals and objectives of the selected decision-making processes, all components of the process and their interrelationships, the resources and constraints of the system, and the measures of system performance. The non-structured interview process included a list of information to gather from a decision maker, but a specific questionnaire was not constructed prior to the interviews. The following sections specify the details of the research methodology.

2. The Research Methodology

The steps of the empirical application of petri nets were:

1. Choose the case study site.
2. Choose the decision-making tasks to model.
3. Choose the interviewees for each task.
4. Meet with each interviewee and collect documentation.
5. Interview decision makers.
6. Construct a petri net model of each task.
7. Verify the model with the interviewees.
8. Amend models as needed.

After each of these research steps is discussed in detail, the descriptions of the decision-making tasks and their petri net models will be presented.

2.1 Choosing the Case Study Site

It was decided that studying several decision making processes at one case study site would be more effective than attempting to study a similar decision making process in a number of sites. This decision was based primarily on time and monetary constraints, specifically the amount of time it takes to become familiar with an agency's overall function. For the reasons stated in Chapter 1, ("narrowing the scope"), a site currently using a GIS was desired. The chosen site was the Washington State Department of Natural Resources (DNR). The reasons for choosing this site included:

- an extensive requirements analysis was conducted and documented before the GIS was implemented, thereby offering a list of expected uses and products;

- the agency is well into the "use" stage of the GIS implementation (seventh year);

- the use of the GIS has been well documented;

- the agency's background and prior use of GIS is known from a site visit performed in 1987 by this researcher, and

- the agency agreed to participate.

The Washington DNR is primarily a forest management operation. The DNR manages forest resources on 2.1 million acres of state-owned trust lands for the trust beneficiaries. The agency's primary mission is to keep these state lands productive and provide financial support to state institutions through land leases and the sale of timber. The DNR is also responsible for natural resource protection and public service. The DNR headquarters is located in Olympia, Washington. The state is divided into seven regions. Each region is divided into districts which are further divided into units. Each regional office supervises the work of the local unit foresters within that region. For a complete description of the site, see (Dickinson, 1988).

The 1987 case study report (Dickinson 1988) identified many of the uses and users of the GIS and the geographic information. Costs and benefits were reported for the overall GIS implementation. However, some of the major benefits from the implementation were not reported, either because they were non-quantifiable, or because many of their uses were poorly understood. It is felt that a better understanding of how the GIS and geographic information is actually used in the agency's decision making will support more accurate reporting of the costs and benefits of the implementation. The current research builds from the previous study, but differs in two distinct ways:

- the description of system use is represented in a structured form (as opposed to the descriptive form used earlier) employing the systems modeling tool of petri nets, and

- costs and benefits will be attached to specific tasks of the agency instead of being reported for the implementation in aggregate.

2.2 Choosing the Decision-Making Tasks to be Modeled

The first step of the case study was to travel to the selected site to choose the specific decision-making tasks to be modeled. Again, because of time and monetary constraints, only four tasks were selected. Four tasks was an acceptable quantity since the objective was to show that a petri net could be used in at least one instance. Much more research will be needed before petri nets are proven in many decision-making environments. The tasks were chosen upon the following criteria:

- the task would have geographic information as an input and/or an output;

- a detailed description of the task's product(s) should exist, (possibly in the requirements analysis document);

- the task should provide geographic information to a decision-making process;

- if possible, the task should use geographic information from the GIS, as well as from other sources;

- if possible, the set of tasks chosen should exhibit various characteristics, such as number of decision makers, length of time for decision, frequency of decision, different levels of complexity, etc., and

- the person(s) involved in the decision making will voluntarily take part in the interview process.

A brief description of the four tasks chosen and their basic characteristics follow. A more detailed description of each task will accompany the petri net representation of these tasks.

Precommercial Thinning Funding Allocation.

This task involves the allocation of DNR funds for the precommercial thinning of specific tree stands. The decision of which stands to thin is made annually by each regional manager and the local unit foresters.

Block Planning.

Five year and longer term timber harvest plans are prepared for contiguous areas of DNR owned lands termed blocks. This decision task involves five to ten people from the various branches of the DNR as well as the regional and local unit foresters. The task is done once for a block area and requires a time frame of over one year.

Old Growth Commission Task Force.

This was a task force of 32 persons (representatives of the timber industry, wildlife groups, trust beneficiaries, Indian tribes, legislators, foresters, etc.) created in 1988 to advise the Commissioner of Public Lands and the DNR on future management of the old growth forests in the Olympic Region. They met monthly for one year and discussed a variety of economical, environmental, and institutional issues.

Fire History Reporting.

This task involved the mapping of fire locations across the state. The map product was used for legislative purposes to gain increased funding for fire control.

2.3 Choosing the Interviewees

Once the tasks were chosen, the next step was to select those people that would be interviewed for each specific task. The interviewees were chosen on the basis of the broadness of their knowledge about the overall decision-making task, the amount of participation in the activity, and their willingness and availability to be interviewed. Figure 20 shows the organizational structure of the DNR. A regional manager was chosen for the precommercial thinning task. Interviewees for the block planning process included members of the Forest Land Management Division, plus regional staff that participated in the processes. The "DNR liaison" for the Old Growth Commission, plus three of the participants (from various backgrounds) were interviewed. The assistant manager of the Fire Control Division was interviewed in respect to the fire history map. An interview appointment was made with each for the next site visit date.

2.4 Initial Meeting with Interviewees

The next step was to meet with representative decision makers of each task to discuss the research and gather as much initial information as possible on the task, particularly explanatory documentation. The initial information collected was used to gain an understanding of what was involved in each decision task. This allowed the researcher to prepare for the interviews in such a way that more interview time could be spent discussing the decision-making process and less spent educating the interviewer on agency policy and general forestry methods.

2.5 The Interview Process

As stated earlier, a non-structured interview method was used. A list of information to gather existed, but a specific questionnaire was not handed to the interviewee. This method was chosen since prior studies of detailed use of geographic information did not exist, and therefore no set of example questions was available. Also, when attempting to gain as much detailed information as possible, it is quite often necessary to restate questions in different formats to gain the needed detail. A third reason for choosing

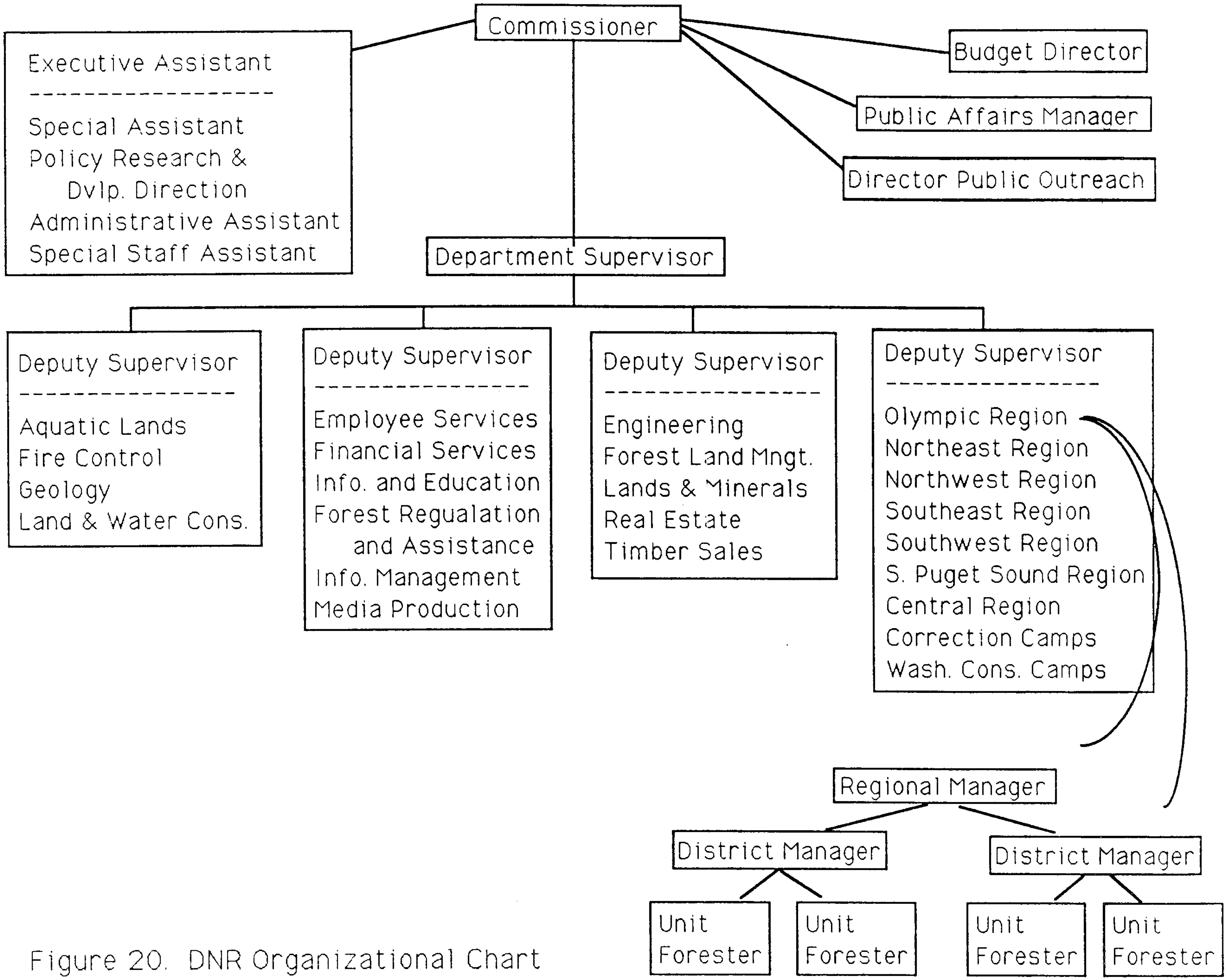


Figure 20. DNR Organizational Chart

this method was the interviewer's lack of experience with the technical terms of forestry management. Indeed, even different interviewees had different definitions of terms and concepts. Furthermore, a number of the interviewees did not understand the technical terms of GIS use.

It was decided that a list of sample questions would be taken to the interview to be used as a guide. This list can be found in Appendix C. It bears repeating that the geographic information was not restricted to products from the GIS, but also included geographic information from other sources such as maps, aerial photography, mental memory, computer models, and tabular data files.

The information received during the interview process was to be used for two objectives:

- to model, in a structured and detailed way, the use of geographic information and its analysis in the selected decision-making processes, and

- to track both the costs and benefits of the geographic information and its analysis for selected tasks.

Specific information to be determined in the interview included:

- the overall goal and specific objectives of the decision-making process;

- the steps involved in the decision-making process;

- the steps involving geographic information;

- the manner of geographic information use (and by whom) in each particular step;

- the type of benefits derived from having this geographic information available during decision-making; and

- the cost incurred by the user to have this geographic information available.

These types of questions were asked for each step along the multi-stage process, not just for the activity as a whole. One problem encountered during the interviews was when the decision maker had been performing the task for quite some time. Because the interviewee no longer thought of each detailed step, there was difficulty in discussing the process at such a level of detail. Another problem occurred with processes that had been performed only a few times or had been introduced recently into the agency. In this instance, the interviewee usually did not have a good understanding of where their decision task fit into other agency decisions.

Collecting the level of detail desired required a rigorous interview schedule. For the two most complex tasks (precommercial thinning and block planning), over ten hours of interview time were required for each task. This was preceded by twenty to thirty hours of preparation time spent on the documentation received prior to the interview. Had the preparation not been performed, probably another ten hours of interview time would have been required. It should also be noted that the block planning process was already represented as a flow chart, and the precommercial thinning decision process represented in an activity-by-month calendar form. The other two tasks consisted of fewer steps and so required less interview time to gain the desired detail of information. Time was also spent learning about the various computer models used outside the GIS, such as the sustainable harvest yield calculator and the intensive stand management simulator. Another task was to collect as much written documentation on the decision-making processes (for later use as background material) and to collect examples of geographic information products.

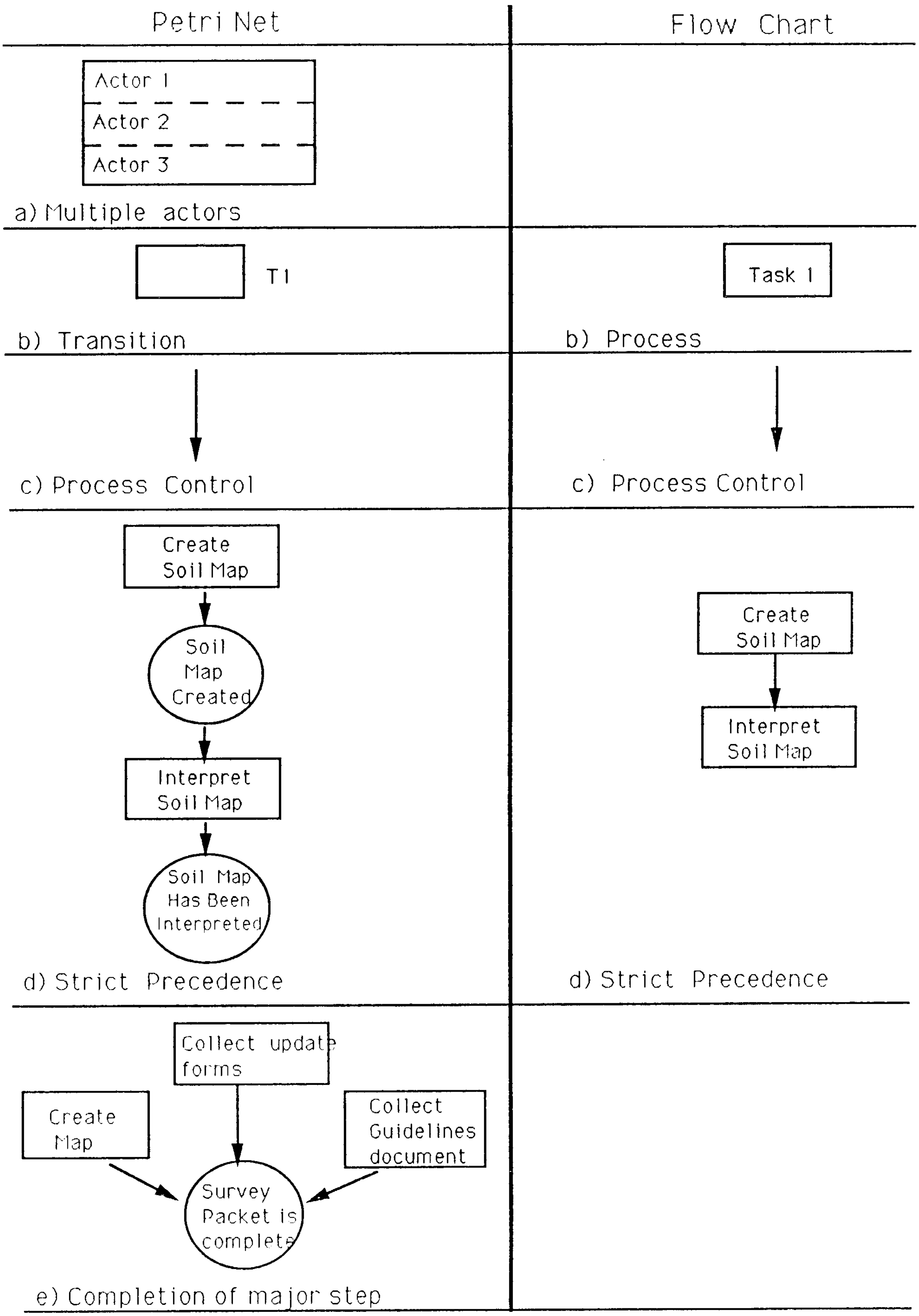


Figure 21.1. Petri Net and Flow Chart Components

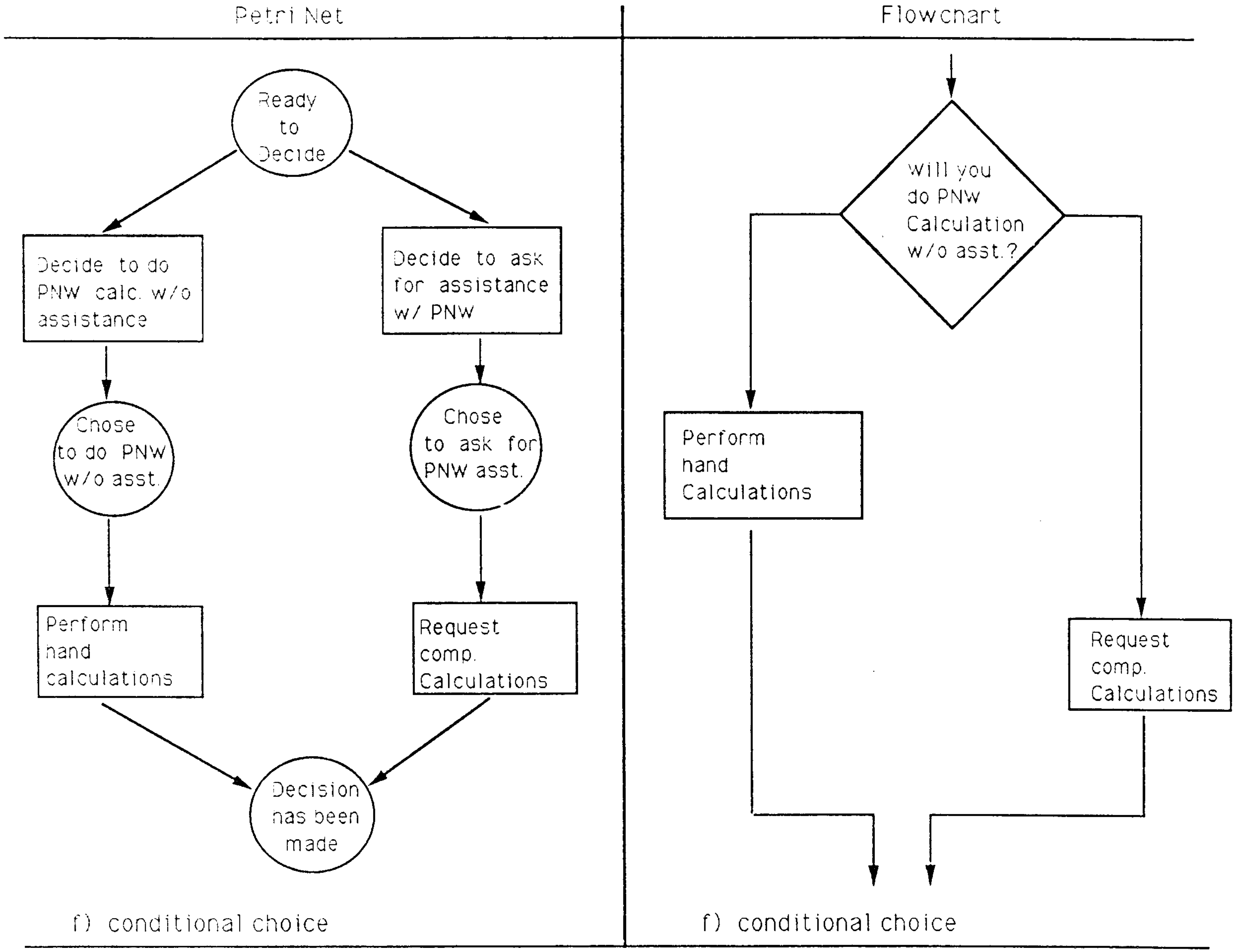


Figure 21.2 Petri Net and Flow Chart Components

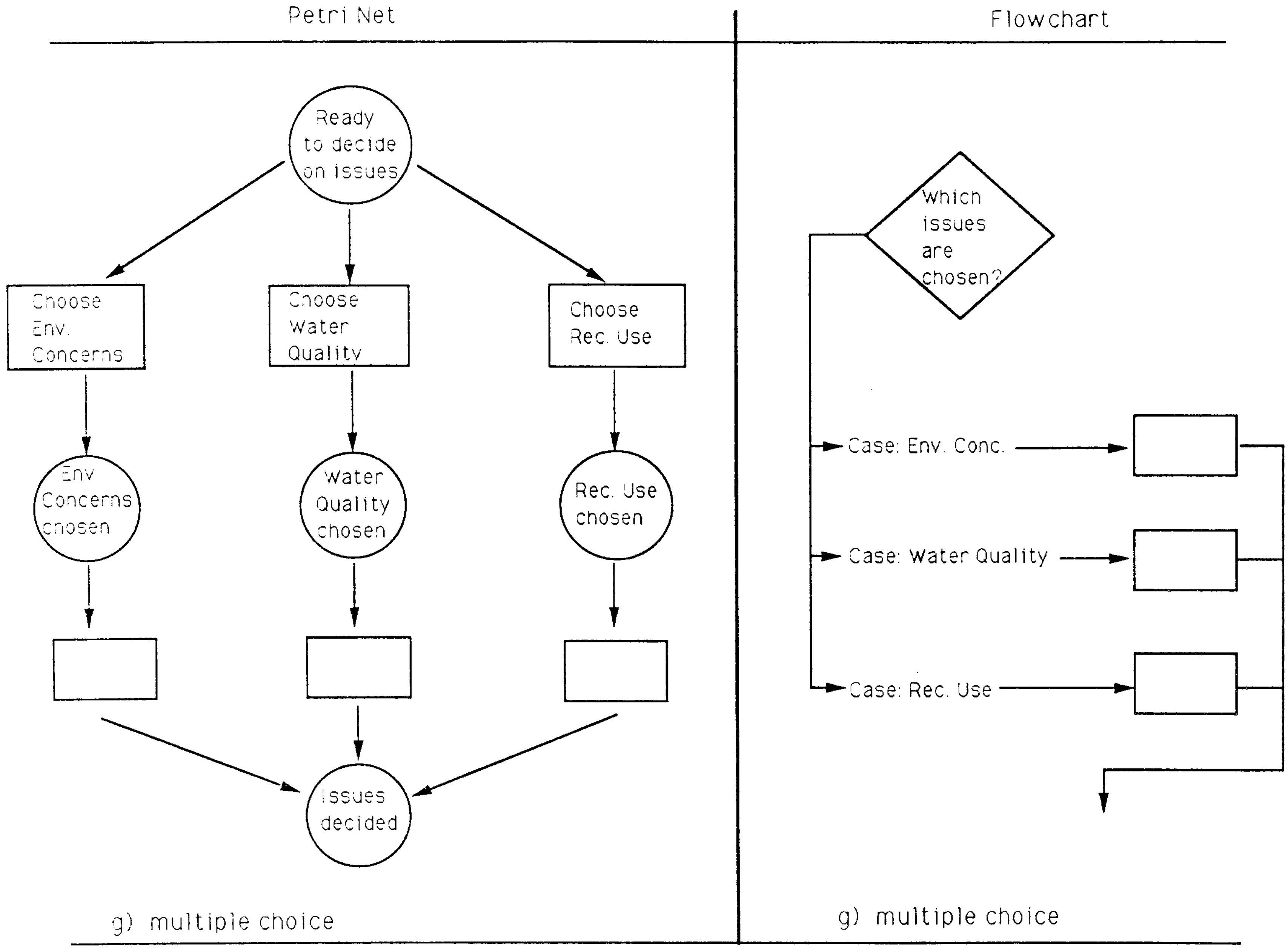


Figure 21.3 Petri Net and Flow Chart Components

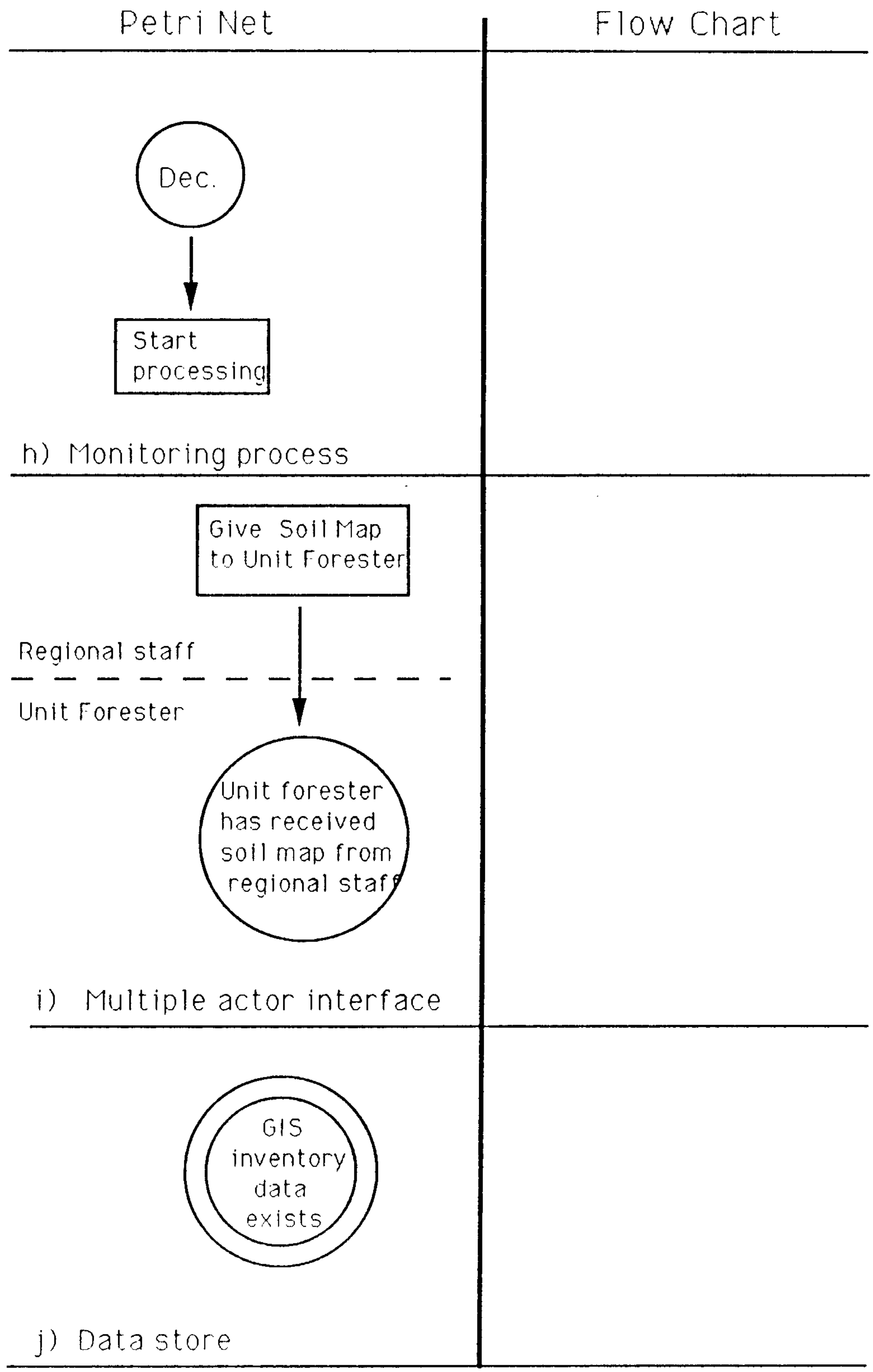


Figure 21.4 Petri Net and Flow Chart Components

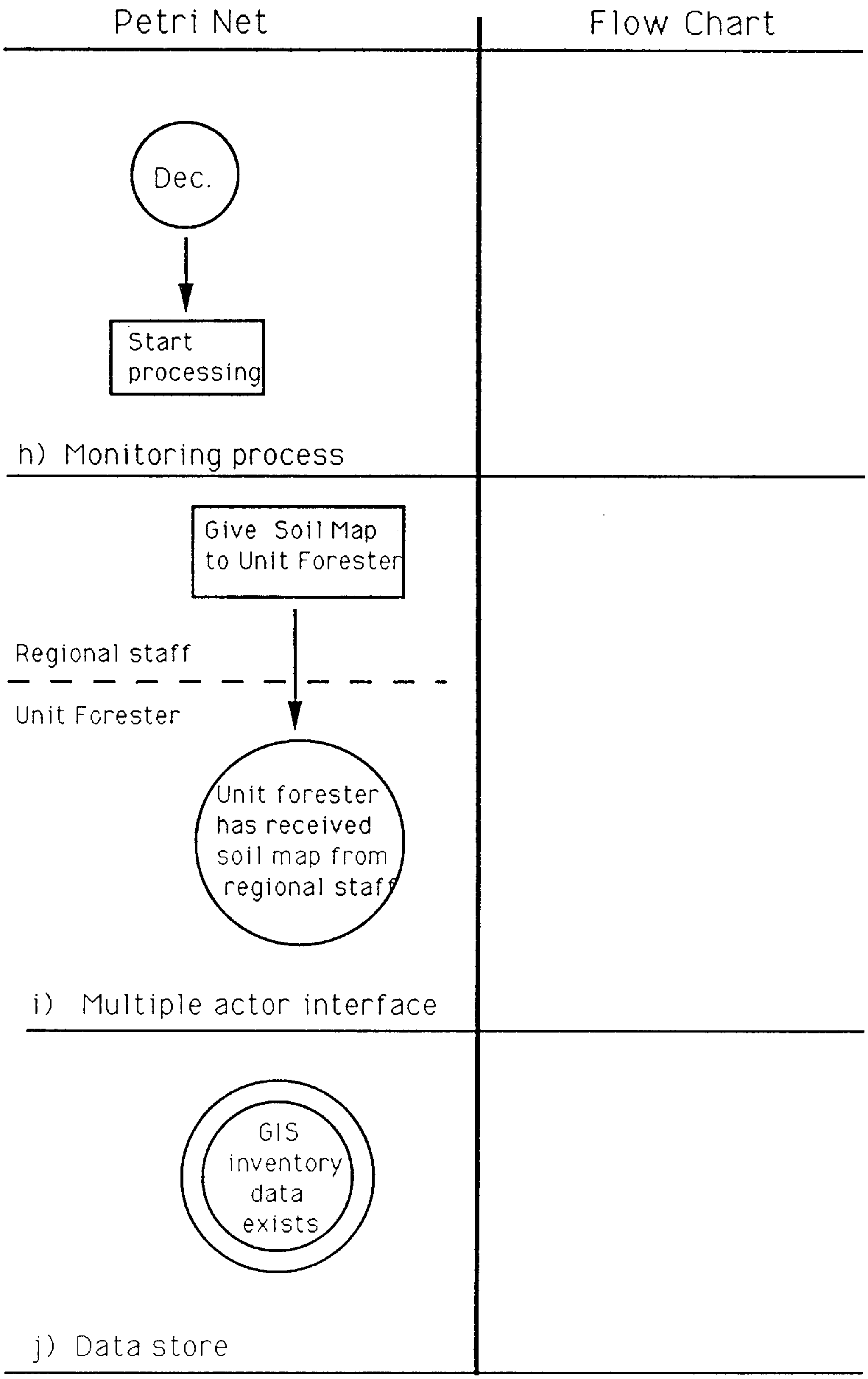


Figure 21.4 Petri Net and Flow Chart Components

2.6 Construction of the Petri Nets

The first part of this step was to create a flow chart of the decision-making process from the information received in the interviews and subsequent documentation. This was done primarily to transform the information in textual form into a graphical form with which the researcher was comfortable. Then the translation of flow chart to petri net could be accomplished. Although there were no formal rules available to guide this translation, some became evident rather quickly. Figure 21 shows the resulting petri net symbology for the various system components and characteristics. Corresponding flow chart components are also shown in Figure 21 for comparison.

The number of actors and the steps performed by each were determined by comparing the flowchart and the documentation. 'Me diagramming space was partitioned into horizontal strips for each actor and labeled with the actor's title (Figure 21.1). The process boxes on the flow chart directly mapped into transition boxes (events) on the petri net (Figure 21.2). The process flow was maintained with directional, open ended arrows in the petri net (Figure 21.3).

The labeling of places (conditions) had to be interpolated subjectively from the sequence of process steps. Five types of places were prevalent:

1. Places representing strict, linear precedence.
2. Places representing the completion of a major processing step.
3. Places representing boolean conditional choices.
4. Places representing multiple conditional choices.
5. Places representing monitoring processes.

Labeling constructs were designed for each type of place and are now described. Labels for the first type of place were simply repetitive of the transition (e.g., if the transition was "create soil map from GIS," the output place was labeled "soil map has been created"). This was the case where there was strict, linear precedence between two transitions (Figure 21.4).

The second type of place was used to represent the completion of a major task (e.g., three processes were included in creating a survey package; the three processes were mapped into three transitions, each leading to the same place labeled "survey package is complete") (Figure 21.5).

A third type of place resulted from the choices possible in a boolean decision. The decision was mapped to two transitions labeled as the possible decisions that could be made (e.g., one transition was labeled "decide to calculate present net worth without assistance from computer model;" the other transition was labeled "decide to ask for assistance to calculate present net worth" (Figure 21.6). One input place was created for the two possible transitions (e.g., "ready to decide whether or not to calculate present new worth without assistance). One output place was created for each transition and labeled as the decision made in the transition (e.g., one place labeled "has decided to calculate without assistance" and the second place labeled "has decided to ask for assistance"). Then the next transition in each path was added. After the last transition in each path, another place was created to re-join the two alternate paths. This place was labeled "decision has been completed."

It is necessary to always begin and end a set of branching alternatives with a place. This allows the input/output matrix for the entire petri net to be maintained. If alternative branches were allowed to re-join at a transition, that transition would have two possible input places, but only be allowed to accept one token. This could not be represented in the matrix form. While this requirement adds more transitions and places to the net, it also forces more structure and more detail.

The fourth type of place represents a conditional choice also, but allows more than two possible choices. This is the equivalent of the case statement in PASCAL. Again, each possible choice in the decision was labeled as a transition (Figure 21.7). For example, the initial place would be labeled "ready to choose which issues to discuss" and the transitions would be labeled "choose environmental concerns," "choose water quality," and "choose recreational use." The output places for each transition would be labeled "environmental concerns are chosen," "water quality is chosen," and "recreational use is chosen," respectively.

The final type of place represents a monitoring process (e.g., the entire precommercial thinning process begins in December; a place labeled "December" acts as a monitor since when it is December, a token would be placed there). A monitoring place appears as a circle with no input arrows from transitions (Figure 21.8).

Interfaces between the multiple actors usually involved the exchange of some document. This was mapped into the petri net by creating a transition at the boundary representing the actor producing the document and a place at the boundary representing the actor receiving the document (Figure 21.9), (e.g., the transition was labeled "give soil map to the unit forester" and the place was labeled "unit forester has received soil map from regional staff"). If an interface occurred without exchange of a document or other object, the transition was simply labeled, "give response to committee" and the transitions was labeled "response has been received from committee."

One addition to the petri net symbology was to add a double circle to represent a place acting as a data store. For example, the place would be labeled "GIS soils data exists" and would lead into the transition "create soils map" (Figure 21.10). A data store that is only "read from" will appear as a double circle with no input arrows. A data store that is read from and/or added to will appear as a double circle with input and output arrows. Data and information flows were not mapped into the initial petri net model. These will be added as tokens later.

It should be pointed out that these rules were not established until after much experimentation had been performed. It is quite probable that more than one set of condition rules could be designed. However, the rules described above seem to offer a useful diagrammatical representation that could be repeated for various decision-making processes.

2.7 Verification of the Model with the Interviewees

Once the initial graphical representation of the petri net was complete, the next step was to return to the case study site to collect any missing information for the process and to allow the interviewee to verify the representation. The conversion from flow chart to petri net seemed to accentuate smaller details that had been omitted in the first discussion. Information such as where calculations were presented, who approved a particular choice, how monetary constraints were included in the decision making, and what condition initiated the entire process are examples of information still needed.

Although a few minutes of explanation of the petri net symbology was required, the representation seemed to perform adequately as a common discussion tool. It was not, however, necessary to explain tokens or matrices of petri nets in this discussion. With the detail of the petri net representation as a tool, missing information was easily added during the second interview. If a process had not been defined in detail, it was easy to sketch a separate petri net for that particular process as the interviewee described its inputs and outputs. Then the interviewee could point out the source of the inputs and termination of the outputs on the larger petri net of the overall process.

Since the processing steps had not been changed dramatically by any new information collected at the second interview, the interviewee was asked to verify that the representation was complete. Since the model showed more detail than ever seen before, they agreed that it seemed complete. They were specifically asked to verify that the model represented all actors and the interfaces between them; all outside data sources had been documented in correct input places; no other alternative paths existed; and all approval steps were represented.

The timing of each process in the decision-making task was also collected at this interview. Both a time frame allowed for each transition, and an actual time required for each transition to be performed were collected. Also during this visit, the interviewee was asked to verify the text prepared to explain the benefits received from the use of the geographic information and analysis in their particular decision-making task.

2.8 Amending the Petri Net Models

The petri nets were re-constructed as needed to include additional information collected at the second interview. A matrix of input and output rules for each transition was also created. The next section will discuss each of the decision-making tasks and the benefits received from having geographic information and the GIS available for the decision making. The petri net representation and matrix will be shown for each task. For an overview of the DNR’s activities, see section 2.1 of this chapter or the complete site visit report in (Dickinson, 1988).

3. Petri Net Representations of Selected Decision Tasks

3.1 Precommercial Thinning Funding Allocation Process

3. 1.1 Background

This decision task involves the allocation of funds to support the precommercial thinning of selected stands of trees. "Precommercial thinning (PCT) is the removal of selected trees early in the timber-growing cycle to concentrate the land’s growing capacity on the optimum number of vigorous, healthy trees. Early in the life of the stand, surveys are conducted to determine the need for thinning. Thinning is most effective when the stand is fully stocked, the canopy is closed and both crown and root systems are beginning to compete for space. The trees have well-defined growth and form and dominant trees are identifiable. These characteristics normally appear when the stand is 10 to 15 years old. During the next decade, precommcrcial thinning will be considered on at least 50,000 acres (5,000+ acres annually)" (FLMP, 1983, p. 14 5).

The major characteristic used to identify a stand for precommcrcial thinning is the percentage of efficient tree crown. Live crown is that part of the tree able to perform photosynthesis. 10% is subtracted from the live crown figure since the lower 10% of the crown is physically unable to perform as much photosynthesis as the upper portion of the tree's crown. Therefore, the efficient crown is defined as the percentage of live crown minus 10%. At approximately 40% efficient crown or less, the ability of that tree to grow and compete is severely limited. The objective is to retain as much efficient crown as possible during a trees' juvenile years to keep growth continuing at a high rate. To retain efficient crown, other trees in the stand must be removed. This process is termed thinning. If efficient crown drops below 40%, that trees' ability to respond to a thinning may take several unproductive years and thus reduce the effect of the invested dollars (Olympic Region PCT Guidelines, 1990).

Generally, a stand allowed to decrease to 30% crown efficiency is termed "stagnant" (from a tree physiology point of view, it is no longer producing girth) and is not expected to produce a positive rate of return upon harvest at 60 years of age. Another method to determine desirability of thinning is to compare the average height of the stand to its age. Expected growth curves can be calculated for each stand. The two axis are age and height of an average tree (Figure 22). If the actual surveyed heights of trees are found to be less than the expected heights, the stand needs to be thinned.

Precommercial thinning is so named because the size of the trees that are thinned are not yet of a commercial size. The trees that are cut are not sold, but simply remain on the ground. This is a very labor intensive task. Therefore, PCT must be viewed as a management activity requiring funding support from within the DNR. Activities providing trees of commercial value, such as harvesting, are not funded by the DNR. These commercial activities are contracted out to commercial firms who bid a price they are wining to pay (based on the value they expect to receive from the timber minus harvest costs). Although it is not a commercial activity, the thinning of a stand is also generally contracted out. In this case the contractors bid a price for which they will perform the thinning and the DNR pays the contractor to perform the task.

However, it is a fact that insufficient funds exist to thin all stands needing to be thinned. This forces each regional manager to choose which of the candidate stands will actually be thinned. Monies are allocated to the regional managers by the Forest Land Management (FLM) Division and in turn these monies are allocated to the local unit foresters.

An average budget for precommercial thinning for the Olympic region is $250,000 per year. On the average, it costs $100/acre to thin a stand. This means funding exists to PCT 2500-3000 acres per year. Calculations based on age of stands and % crown efficiency indicate that approximately 5000-8000 acres should be precornmercially thinned per year. (Some of this difference can be handled by DNR work camps, (i.e., free labor) but not all). It is up to the regional manager to distribute the available PCT funds to different unit foresters.

Therefore, the decision is to allocate scarce monetary resources for the annual activity of precommercial thinning. The problem is that there is not enough funding to thin all stands that should be thinned. Prior to the use of the GIS, the choice of which stands to thin was made in the following ways:

1. PCT funding monies were divided evenly among the 13 units in the Olympic Region.

2. Local Unit Foresters then chose which stands to thin. This decision was based on the foresters field experience and recollection of stands nearing 40% crown efficiency. Stands located nearer to roads were chosen first since it was more economical to reach these stands than to build new roads to reach other stands.

3.1.2 The Decision-Making Process

Currently, choosing which stands to thin is decided through the process shown in Figure 23. The primary differences in the current process (as compared to the previous process) include:

1. A list and map of all candidate stands for PCT
(age > 15 years and crown efficiency < 70%) is available.

2. All candidate stands are ranked by their present net worth (PNW).

The first twelve steps (those labeled "Pre-PCT Survey") are performed to collect all information that will be needed to allocate the PCT funding. Any stand that is between the ages of 15 and 18, or any stand which has never been surveyed, is a candidate for thinning. Every candidate stand should be field surveyed by the unit forester.

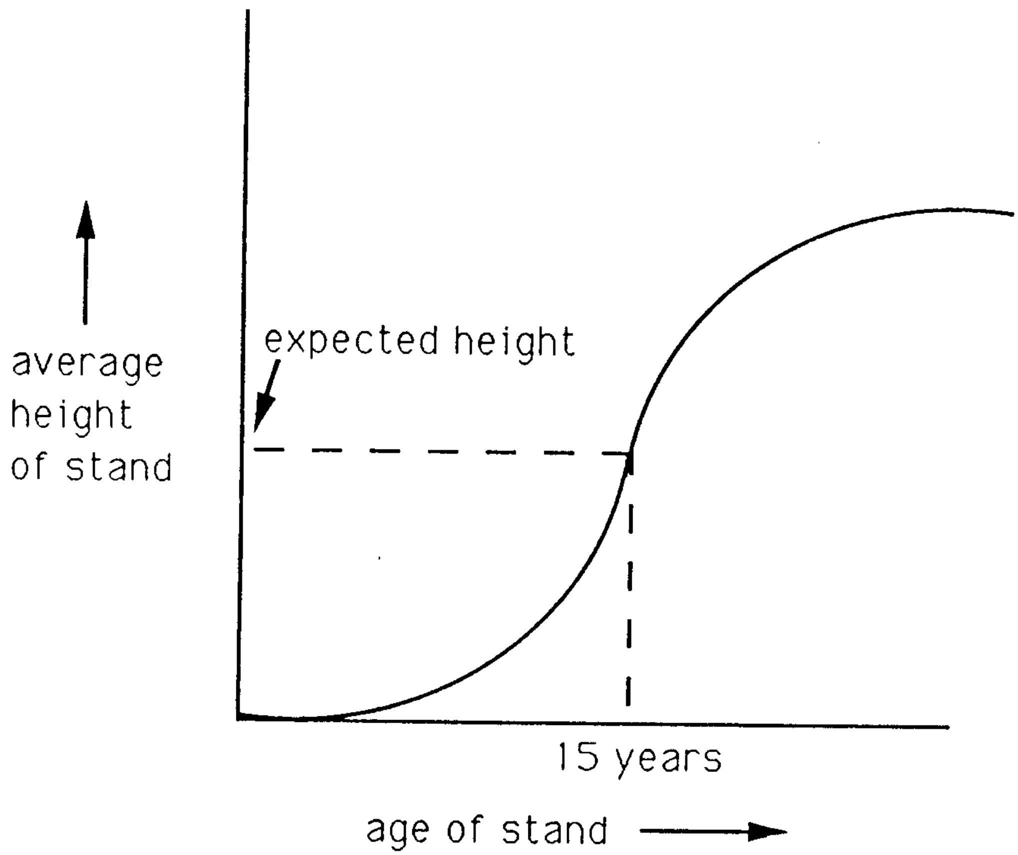
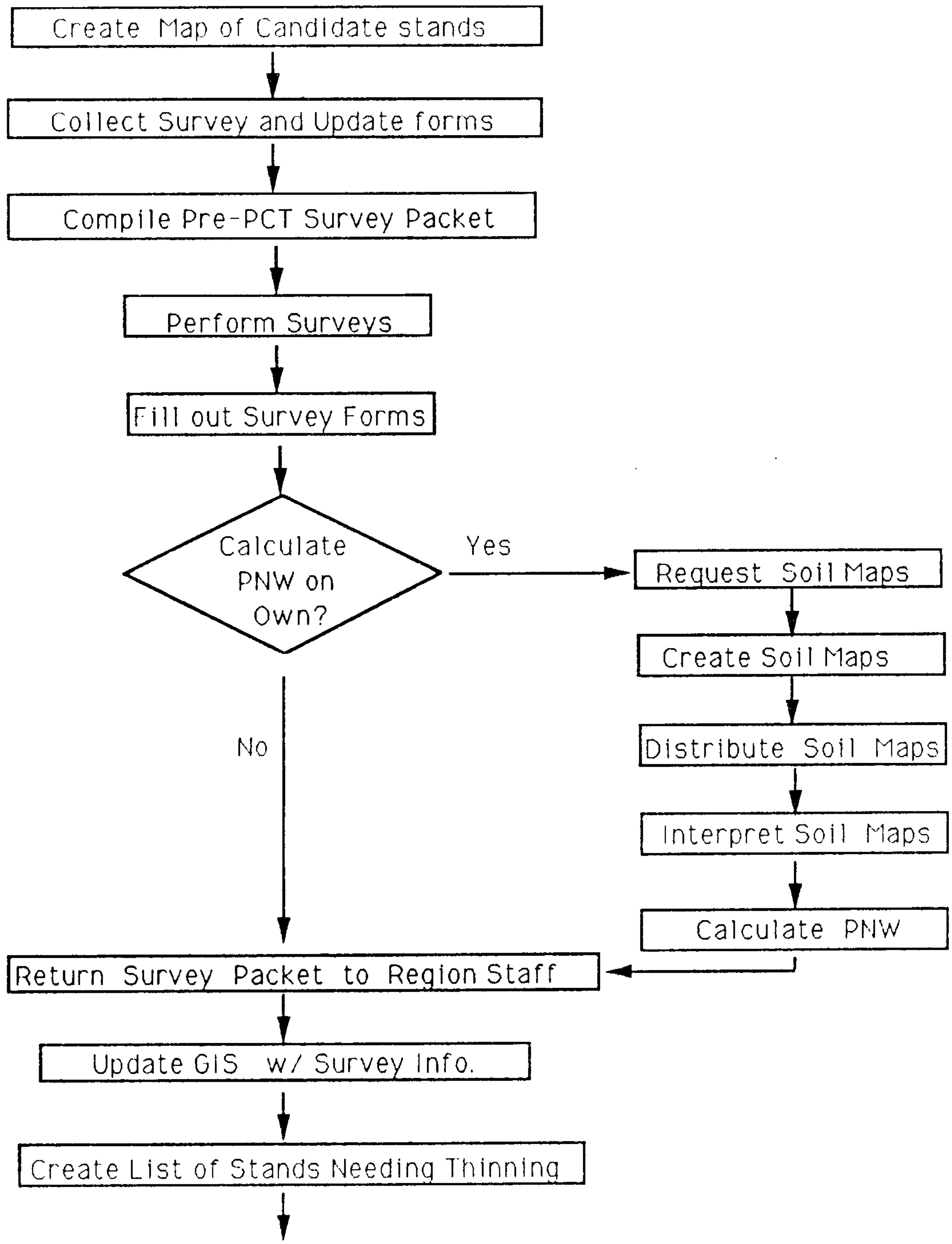


Figure 22. Expected Growth Curve



(figure cont. on next page)

Figure 23. Flow Chart: PCT Funding Allocation Process

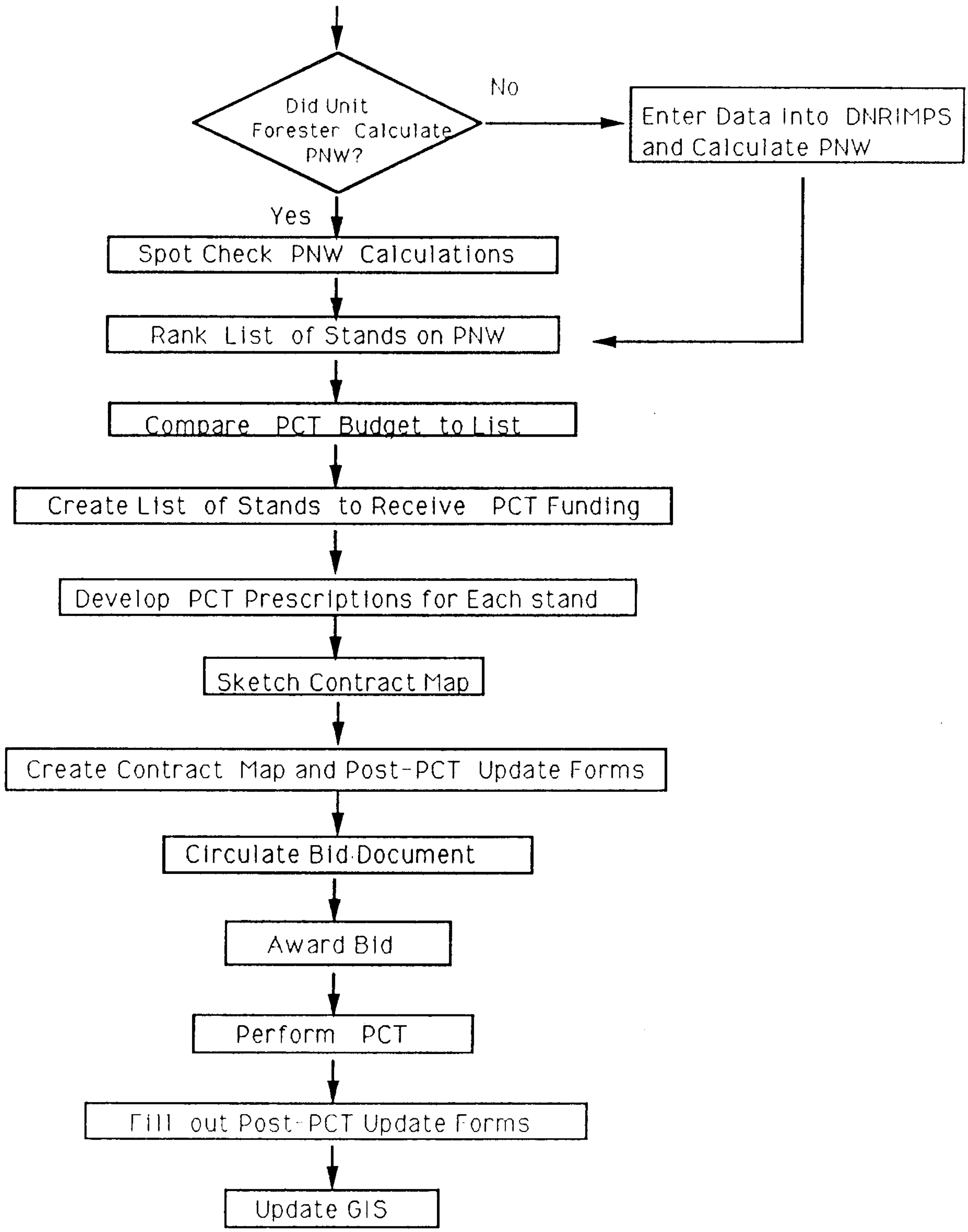


Figure 23. Flow Chart: PCT Funding Allocation Process (cont.)

A PNW value must be calculated for each stand that needs thinning. For the purposes of PCT, PNW is calculated from the expected yield of a stand on a particular soil type. The unit forester can either choose to calculate the PNW on his own (with the use of PNW tables and a soils map of the stand area to show growth capability) or he can choose to let the regional staff calculate the values with the use of a computer program called DNR Intensive Management Program Simulator (DNRIMPS).

The list of stands needing to be thinned is created by selecting all stands that have a crown efficiency between 40% and 70%. This list is then ranked according to the PNW of each stand. If the unit forester calculated his own PNW values, the region staff spotchecks the values for accuracy. If the unit forester did not calculate the PNW values, the region staff will enter the survey data into the intensive management simulation model which will produce the needed PNW values for each stand.

The next step is to compare the list of all stands needing to be thinned with the funds available for PCT operations. The funding level available is always less than the cost to thin all the stands on this list. Generally, those stands with the highest PNW values will receive the available PCT monies. One exception to this is a lower priority candidate stand which is approaching the minimum acceptable % live crown, i.e. "if the unit is missed this year or next it may be too late for that unit to recover from less than 40% crown in an acceptable length of time," (Olympic Region PCT Guidelines, 1990).. Another exception is when the proximity of a lower priority stand to road access provides a more economical use of funds. The region staff creates the list of stands in each unit that will actually receive PCT funding.

At this time, the unit forester will develop a prescription for the thinning of each stand. This prescription is a set of guidelines such as how many stems per acre to thin, particular measures to be taken to ensure preservation of water quality or wildlife habitat, and restrictions on road placement. The unit forester also sketches any locational information that should be shown on the contract map. An example of a contract map is shown in Figure 24.

The region staff then takes the prescription information and map sketch and creates a bid document which is circulated to outside contractors. The job is awarded and the thinning is performed. The final step required in the thinning contract is to provide updated stand information which the region staff uses to update the GIS inventory database.

3.1.3 Petri Net Representation

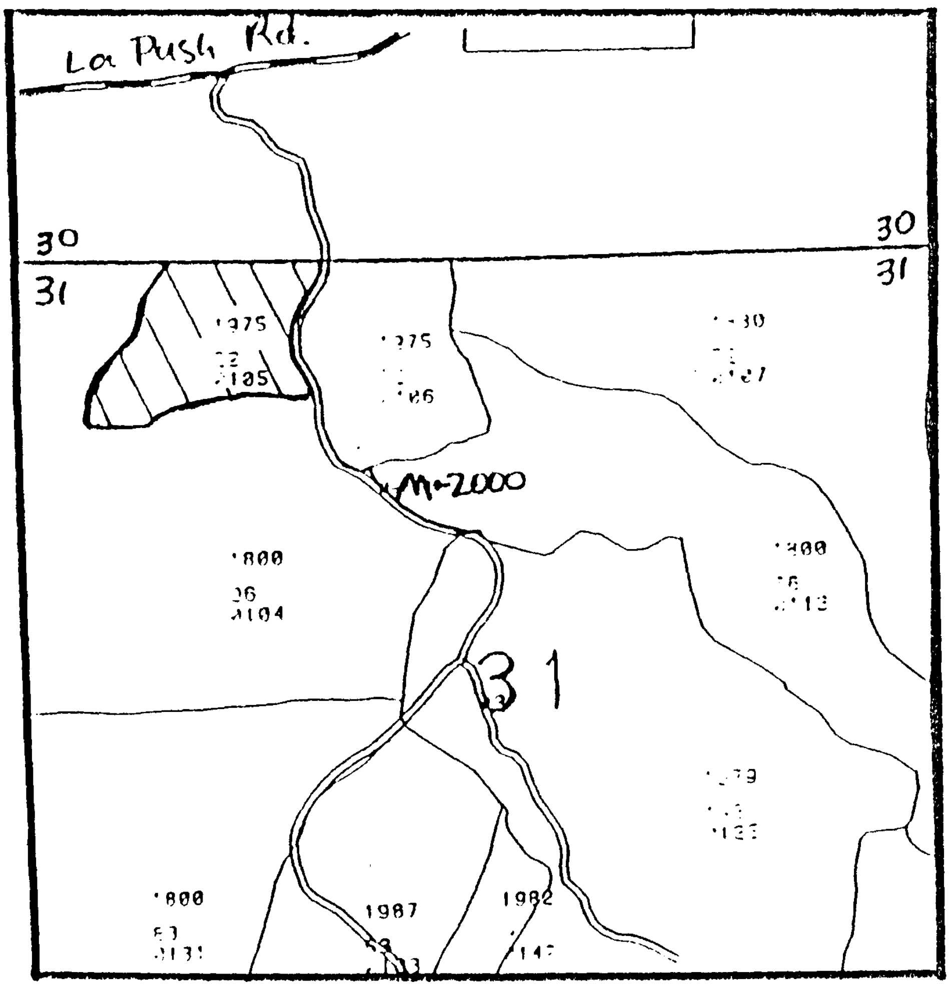
The petri net representation of this process is shown in Figure 25. The petri net was constructed with a general flow from left to right for readability convention. The numbering of the places and transitions follows this general flow, although exceptions do exist where alternate paths or loops are prevalent. The labels for each place and transition are:

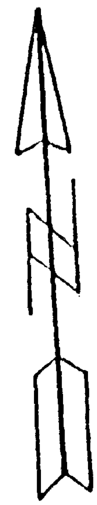
CONDITIONS (STATES)

PI = December I
P2 = Pre-PCT survey packet is complete
P3 = Survey forms exist
P4 = Unit forester has received Pre-PCT survey packet
P5 = Surveys have been completed
P6 = Unit forester is ready to decide whether or not to calculate PNW on his own

Region OLYMPIC District HOH Local BOGACHIEL Grant 3
County CLALLAM Section 31 Twp. 28 North, Rge.14 W.W.M.
Unit Name LAPUSH U-1 Item No. 1 Unit No. BOG-8
App. No. 35176

Scale 1" = 1,000'





LEGEND

PVT Private Ownership
Unit Boundary
Scattered Trees (walk through)
Road
1982 Origin Date
Concentrated Acres
Buffer (no treatment)
Stream

Vicinity map See reverse side

FOR DNR USE ONLY

STAND DATA Stock % Conifers ____

Species	Order	Stems/Acre	Origin Year	DBH	Basal Area
	1				
	2				
	3				
	4				

Exam Type:
Field Observation (visual)-2 ____
Field Plots - 3 ____
Low Intensity Field Survey-5 ____

Figure 24. Sample Graphic: Contract Map (Vaughan, 1990)

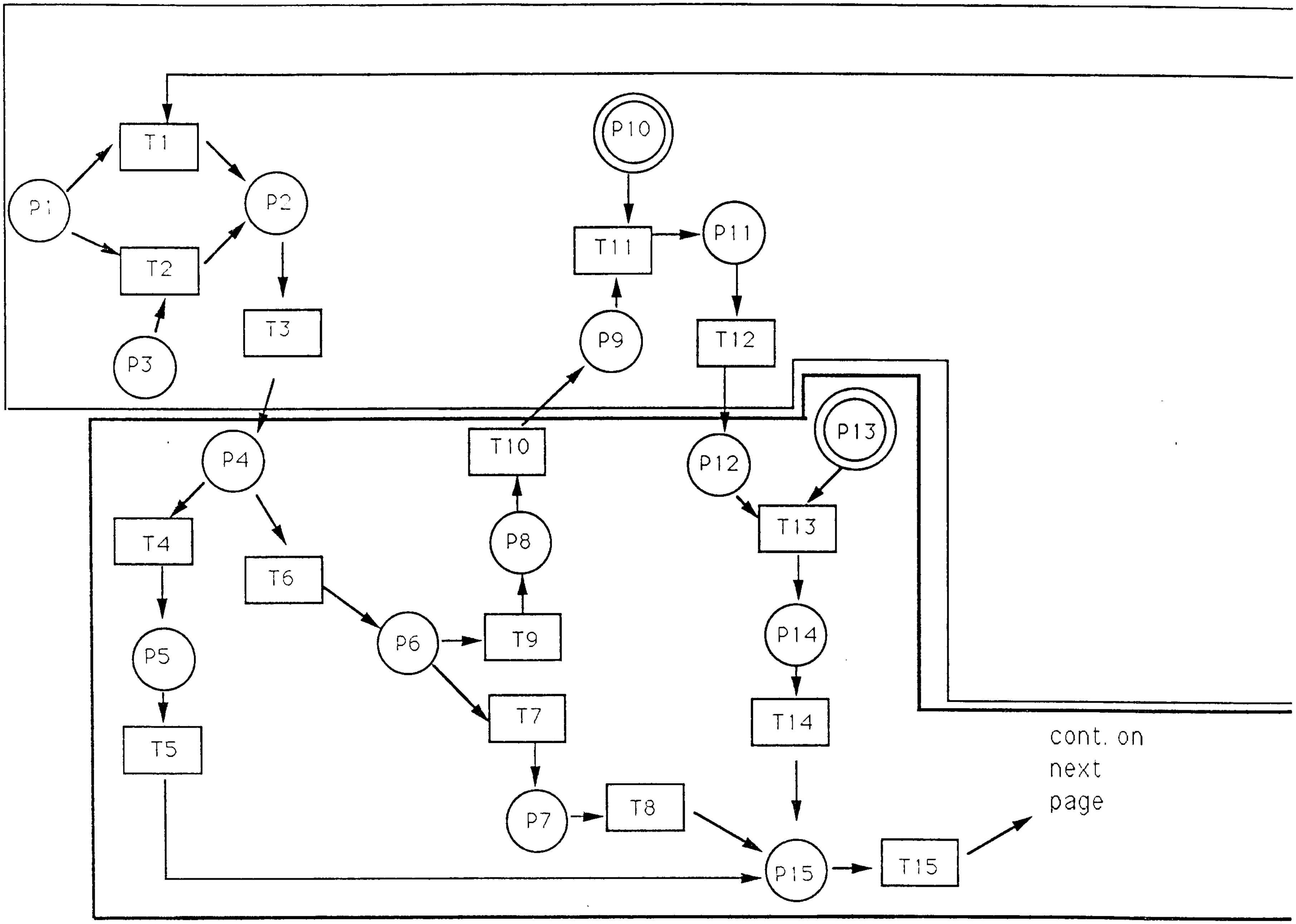


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Figure 25.1 Petri Net: PCT Funding Allocation Process

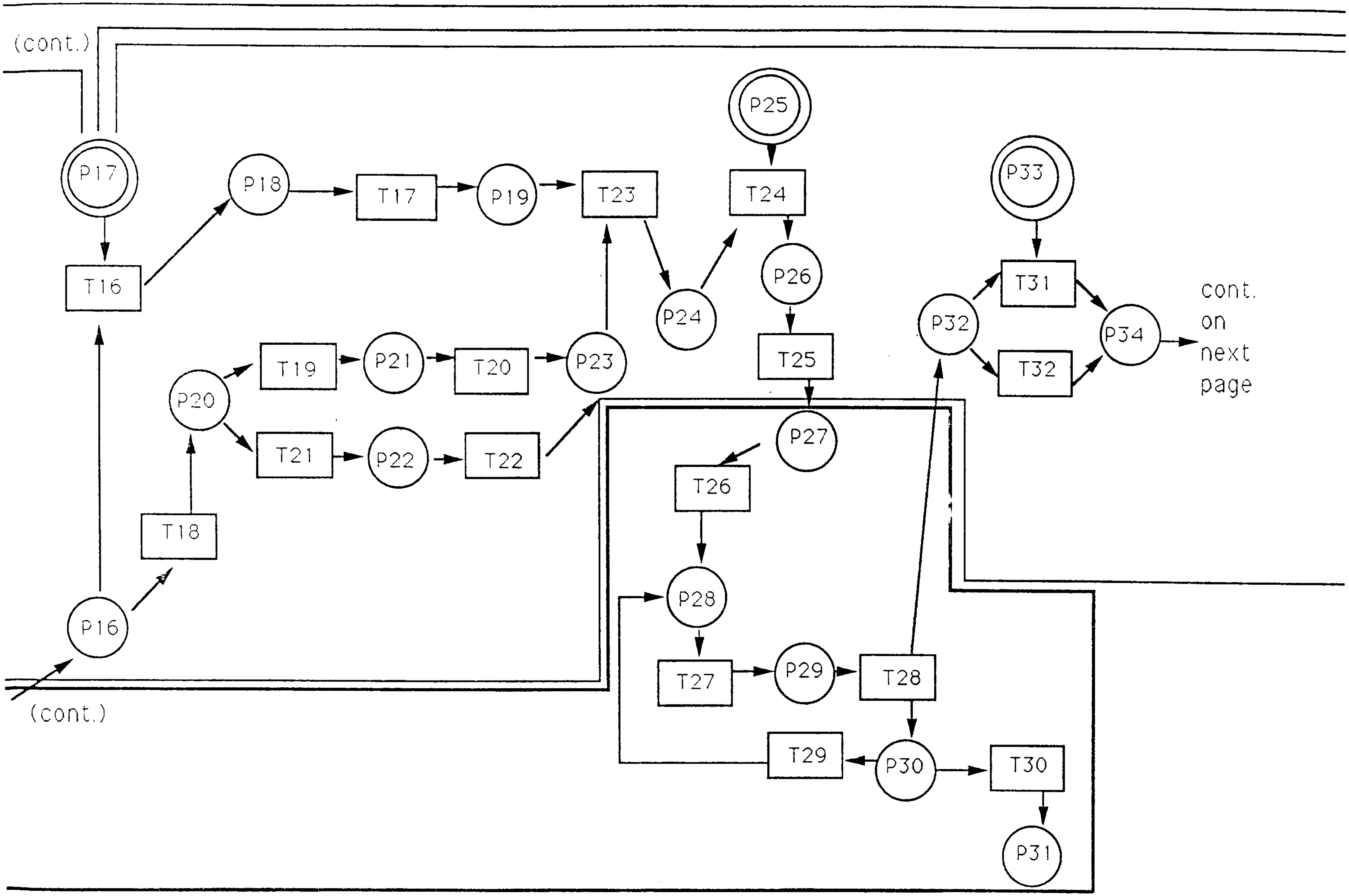

Figure 25.2 Petri Net: PCT Funding Allocation Process

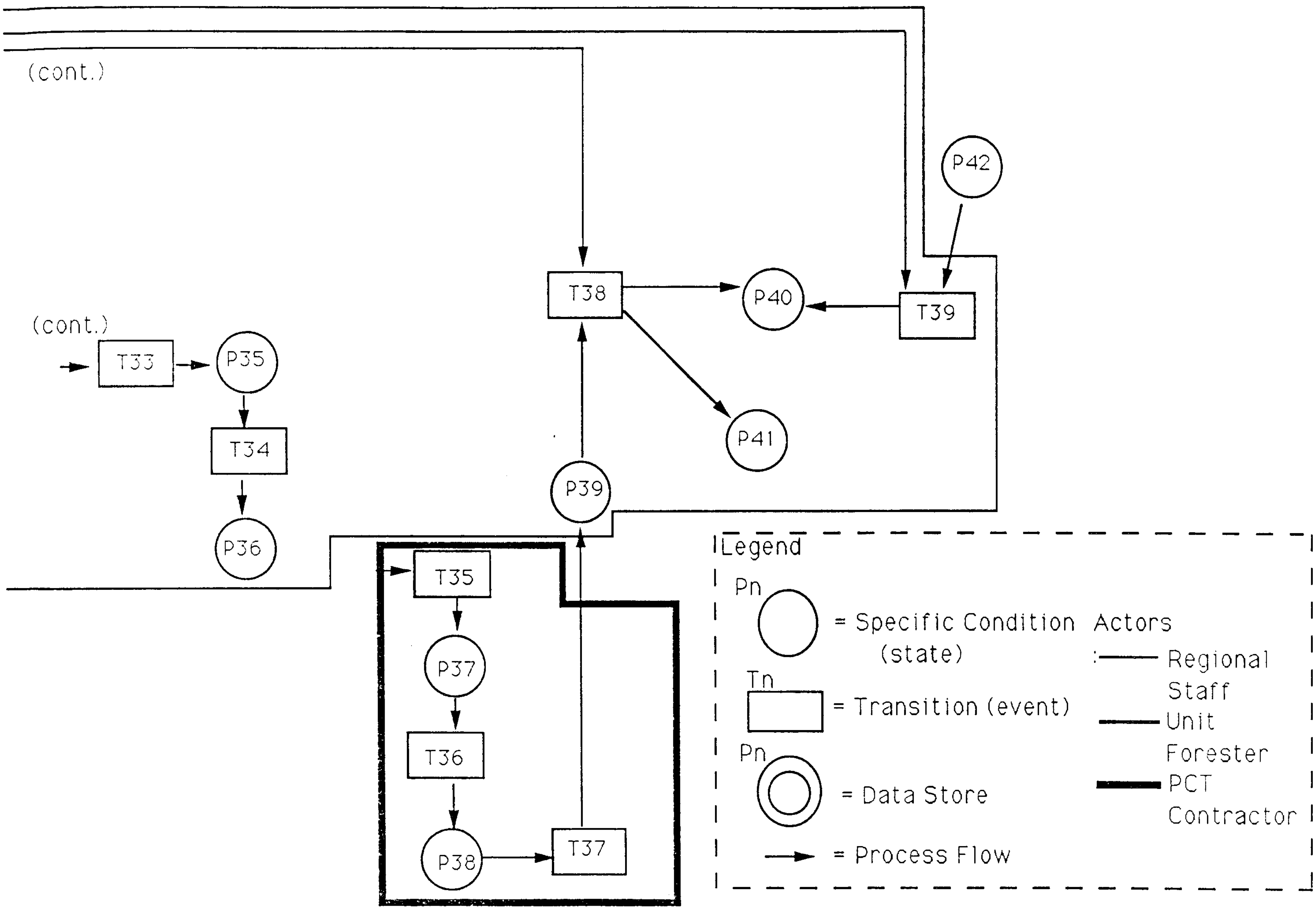

Figure 25.3 Petri Net: PCT Funding Allocation Process

P7 = Unit forester has decided to let regional staff calculate PNW
P8 = Unit forester has decided to calculate PNW on own
P9 = Region staff has received request for soils map
P10 = GIS soils data exists
P11 = Soils Map has been created
P12 = Unit forester has received soils map
P13 = PNW tables exist
P14 = PNW has been calculated
P15 = Pre-PCT survey has been completed
P16 = Region staff has received Pre-PCT survey packet
P17 = GIS inventory database exists
P18 = GIS inventory database has been update
P19 = List of all stands needing thinning is complete
P20 = Information on PNW calculation has been found
P21 = The need to do PNW calculations exists
P22 = No need exists to calculate all PNW values
P23 = PNW calculations for all stands have been performed
P24 = all stands (for all units) have been ranked on PNW
P25 = PCT budget figures exist (from FLM Division)
P26 = List of stands that will actually be PCTed is complete
P27 = Unit forester receives list of stands to be PCTed
P28 = A stand requires a prescription and a contract map needs to be sketched
P29 = PCT prescription and contract map sketch are finished
P30 = Unit forester is ready to do next prescription and sketch map if needed
P31 = All prescriptions and sketch maps are completed
P32 = Region staff receives prescription and map sketch
P33 = GIS basemap information exists
P34 = PCT bid document is complete
P35 = Ready to award bid for PCT job
P36 = Outside contractor has been chosen
P37 = PCT is complete
P38 = Post-PCT update forms have been completed
P39 = Regional staff has received Post-PCT update information
P40 = GIS inventory has been updated
P41 = Funding allocation process is complete
P42 = January 1

Transitions (Events)	Actor*
T1 = Create map of candidate stands from GIS (sort by local unit, 15<age<18, not surveyed yet)	RS
T2 = Collect survey and update forms	RS
T3 = Give Pre-PCT survey packet to unit forester	RS
T4 = Perform surveys	UF
T5 = Fill out survey/update forms	UF
T6 = Evaluate criteria to decide whether or not to do PNW calculations on own	UF
T7 = Choose not to do PNW calculations on own	UF
T8 = Write down that PNW will need to be	UF

	calculated later	
T9 =	Choose to do PNW calculations on own	UF
T10 =	Request soils maps for stands	UF
T11 =	Create soil maps (from GIS)	RS
T12 =	Give soil maps to unit forester	RS
T13 =	Calculate PNW for all candidate stands	UF
T14 =	Write PNW values into a document	UF
T15 =	Return Pre-PCT survey packet to regional staff	UF
T16 =	Enter survey data into GIS inventory database	RS
T17 =	Create list of candidate stands (GIS sort: 40% < crown eff. < 70%)	RS
T18 =	Locate part of survey document that discusses PNW calculations	RS
T19 =	Determine that U.F. did not do PNW calcs.	RS
T20 =	Enter data into DNR IMPS and run to produce PNW calculations	RS
T21 =	Determine that U. F. did own PNW calcs.	RS
T22 =	Spotcheck unit forester's PNW calculations	RS
T23 =	Rank stands on PNW	RS
T24 =	Compare list of "Stands to PCT" to available "budget to PCT"	RS
T25 =	Give list of stands to actually PCT to U.F.	RS
T26 =	Take stand at top of list	UF
T27 =	Develop PCT prescriptions and sketch contract maps for stand	UF
T28 =	Return prescriptions and sketch to R.S.	UF
T29 =	Determine there are more prescriptions and sketch maps to do	UF
T30 =	Determine there are no more prescriptions nor sketch maps to do	UF
T31 =	Create contract map and update forms on GIS	RS
T32 =	Create text for PCT prescription	RS
T33 =	Circulate PCT bid and collect awards	RS
T34 =	Award bid	RS
T35 =	Perform PCT	OC
T36 =	Fill out Post-PCT update form	OC
T37 =	Return Post-PCT forms to R.S.	OC
T38 =	Enter updates into GIS inventory database	RS
T39 =	Decrease crown efficiency by 3% for each stand in GIS inventory database	RS

*RS = Regional Staff
UF = Unit Forester
OC = Outside Contractor

Three actors are defined: the regional staff, the unit forester, and the outside contractor. The processes performed by each are surrounded by a boundary line (see legend). Each unit forester performs the processes shown for that actor. This requires that the interfaces between the region staff and the unit forester (T3 to P4, T10 to P9, T12 to P12, T15 to P16, T25 to P27, and T28 to P32) must be repeated for each of the units in the region.

This is the same process seen in the flow chart in Figure 23. The structure of the petri net forced a need to collect more detailed information. Monitoring functions were added at P1 and P42. December I is the start date for this entire process. The January I monitor is actually automated in the computer. The date of January I triggers a simulation event which decreases the crown efficiency of every stand by 3%. This allows the inventory database to be kept "up to date" even when stands are not surveyed for ten or fifteen years. Another addition of detail was process T18. The flow chart assumed the region staff knew if PNW had been calculated by the unit forester.

There is still more detail that could be added to the model. For instance, T22 involves spotchecking the PNW calculations performed by the unit forester. There is probably a verification loop that should be included at this point. What happens if the calculations appear to be incorrect? How much accuracy is required? Interfaces to entities outside the "system" could also be added. For example, P25 is a link to the budget process in the Forest Land Management Division.

The matrix in Figure 26 shows the input and output relationships between the transitions and places in the petri net. The matrix is most easily read by rows. For each transition, a "-I" is placed in the column of any input places to that transition. Likewise, a "I" identifies each output place from that transition. The first row shows that T1 requires an input token from PI and PIT Uponfiring, T1 outputs a token to P2. (It should be stressed that this is not a colored petri net, only a basic petri net. Therefore, the tokens only represent conditions which hold true.) The next row shows that T2 requires a token from PI and P3 and outputs a token to P2. The "-I" or "I" are not the number of tokens required; this matrix only shows the input/output relationships.

It may seem that the matrix shows the linearity of this decision-making process. However, this is only a function of the numbering process followed in labeling the petri net.

3.1.4 Benefits of Geographic Information and Analysis

Three distinct benefits were documented from the use of geographic information and analysis in the decision-making process (Vaughan, 1990). Each benefit is described in detail below. It is realized that these benefits are only descriptive. Chapter 5 will conceptualize how these benefits may be shown in the petri net. The discussion of benefits here is provided to complete the explanation of the decision-making task.

Benefit: Increase in monies made available from FLM Division for PCT activities. Increase was from $200,000 in FY89 to $1 million in FY90.

Part of this increase is attributable to the ability to demonstrate the need for more PCT funding to support the level of PCT necessary to maintain positive rate of returns on as many stands as possible. Scientific calculations of predicted stand yields, present net worth, and rates of return help create a list of all stands that need thinning to maintain a positive rate of return. Comparing the current PCT funding level to the monies required to PCT all stands on this list will show a concrete need for increased funding. By simulating the decrease in crown efficiency per year, predictions of future level of PCT funding could also be documented.

Benefit: Increase in PNW (i.e. rate of return on dollars spent on precommercial thinning) of stands.

The overall rate of return on stands can be increased by producing a map of all stands requiring PCT attention. Displaying all stands with a crown efficiency of 40% or less and all stands greater than 23 years of age, protects the forester from having to rely on his memory to single out stands requiring thinning. Without such a map, stands not often visited may be forgotten until the crown efficiency is too low for the stand to respond favorably to PCT.

Funding for precommercial thinning comes from the FLM division. The FLM division receives a proportionate amount of all funds available to the DNR for stand management. The monies for stand management are taken as a percentage of the overall revenue produced by all state-managed lands. Therefore, by increasing the overall PNW of stands, the overall revenue is increased, and so are the funds available for stand management.

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38	P39	P40	P41
T1	-1	1															-1																								
T2	-1	1	-1																																						
T3		-1		1																																					
T4				-1	1																																				
T5					-1										1																										
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T38																	-1																						-1	1	
T39																	-1																							-1	1

Figure 26. Petri Net Matrix: PCT Funding Allocation Process

-1 = input to a transition
1 = output from a transition

Benefit: More profitable allocation of PCT funds

Generally, the funds available to PCT are less than needed to thin all stands requiring thinning. By ranking the stands on PNW, those with the highest rate of return will receive PCT funding first. Prior to a ranking system, each unit in the region was given a share of the monies available and the unit forester relied on his memory to decide which stands to thin. Now, the ranking system allows those stands with the highest rate of return to be thinned first.

For example, a high ranking PNW may be $1200 while a lower ranking, yet positive, PNW may be $150 (dollar amounts are discounted at 7%). Assume the PCT funding available would allow only 50% of all candidate stands to be thinned. By ranking the stands, the maximum possible PNW is attained by thinning the top half of the list. Without the ranking, it is highly unlikely that these maximum PNW stands would have been chosen. This would mean a lower overall PNW would have been attained (Figure 27). Furthermore, the ranking is performed across all units, collectively, so the entire region’s PCT funding is best allocated over all stands managed by that region. The location of candidate sites and their proximity to roads and work camps could also support better allocation of funds.

3.2 Block Planning Process

3.2.1 Background

Planning of DNR managed forested lands conforms with the ten year planning cycle of the Forest Land Management Program (FLMP). The Forest Land Management Program adopted a "block/drainage" format as the basic building block for departmental planning. A drainage is the watershed of a stream or body of water including all tributary streams (FLMP, 1983). "Blocks" are large DNR ownerships which contain a large contiguous area (between 20,000 and 30,000 acres) of forested land which has common, identifiable issues or concerns. The area in a block may be prone to landslides, act as a critical wildlife habitat, include highly erodible soils, be a high use area for public recreation, or involve a high visual impact of the harvest, to name a few. Issues such as these require the block plan to incorporate solutions via a public planning process. The block plan forms a bridge between the FLMP and site-specific activities (Probst, 1987).

The block planning process involves an issue analysis which leads to a Forest Management plan for the next ten years. The plan delineates the general areas to be harvested (logging units), the expected amount of cut by age, the sequence of cuts, and a proposed road system to be used for harvesting. The block plan will also prescribe necessary precautions for the protection of sensitive areas.

Forty-seven potential block plan areas have been identified in the state of Washington at present. Three plans have been completed and two are in progress now. The Forest Land Management Division (FLMD) is responsible for the review, approval and monitoring of the block planning process. Persons involved in the decision-making process are the Regional Manager, District Managers and Unit Forester of the block plan area, and any specialists required for the sensitive issues (i.e., wildlife biologist, recreational manager, etc.). Geographic information required for this process could include ownership, landuse/landcover, topography, soils, hydrography, roads, and sensitive issue areas, among others.

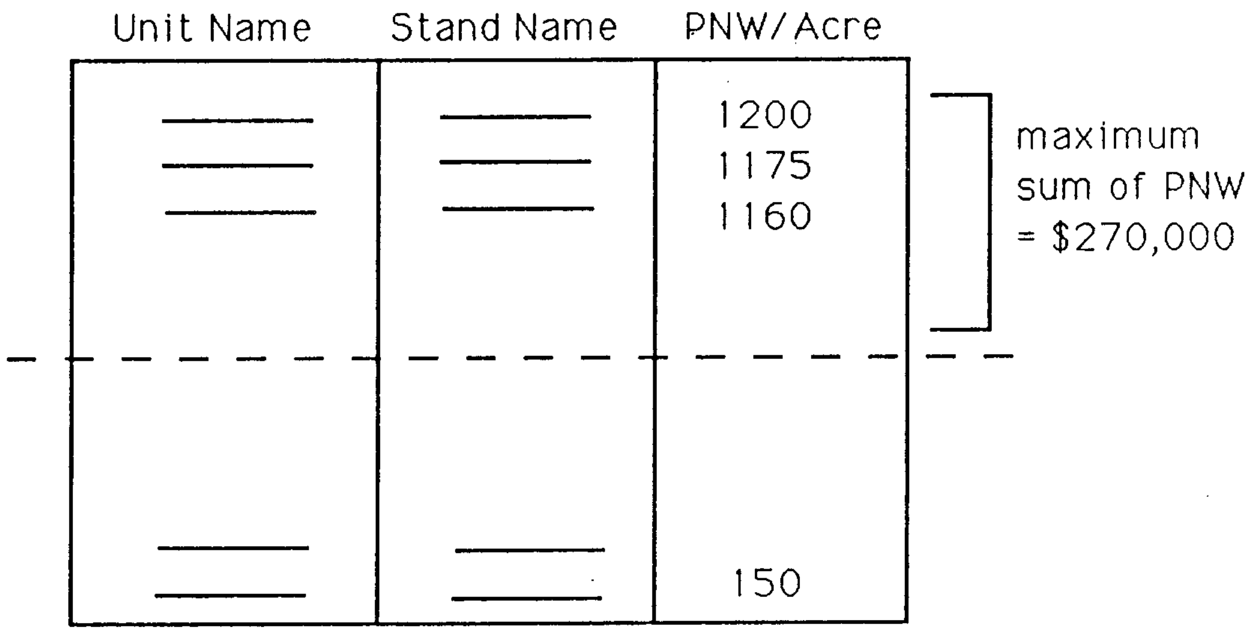

Figure 27. Example List of PNW for Stands

3.2.2 The Decision-Making Process

The block planning process is shown as a flow chart in Figure 28. The initial task of the process is to define an area that will require a block plan. The sensitive issues of the area are discussed and used as a guide for delineating the boundary of the block. A briefing paper is prepared and presented to executive management for approval (step 2). If acceptable, executive management approves the use of time and monetary resources to design the block plan.

The third step involves selecting the necessary staff to comprise the planning team. A work plan is created and presented to executive management for approval of staffing changes. The next step is to solicit external issues from the public. Maps of the proposed block area are provided at a public meeting. Citizens note the location of the sensitive areas they are aware of on these maps. The fifth step involves the generation of the actual block boundary map and a list of the sensitive issues.

The sixth step begins the actual process of designing a block plan. The goals and objectives, as documented in the FLMP, are identified. The Forest Management goal is to "provide a forest management focus that will meet trust obligations, support statewide sustained yield timber management, integrating public use and providing environmental protection" (Tahuya State Forest Management Plan, 1990, p. 14). Specific objectives are established for the block area. An example of site-specific objectives is taken from the Tahuya State Forest:

- apply site-specific decision on cutting age to increase the diversity of age classes;
- provide a basis for resource management beyond the ten-year scope of this plan;
- continue to manage for specialty forest products and other nontimber uses;
- reduce risk of wildfire from forest management activities.

(Tahuya State Forest Management Plan, 1990, p. 14)

An example of site-specific harvest guidelines is taken from the Capitol Forest Block Plan:

- maintain the sustainable harvest volume
- spread cut evenly over the three drainage areas
- cut no more than 100 contiguous acres
- provide a ten-year green-up period between adjacent cuts
- cut oldest trees first
- after harvest, convert hardwood stands to conifer
- minimize road costs
- minimize soil damage
- minimize logging costs (Poch, 1990)

Step seven of the block planning process involves collecting all necessary data based on the special-issues lists generated from the internal and external scoping of issues. Figures 29 and 30 are examples of information products used for the Tahuya State Forest plan. Step eight is the actual construction of the plan and involves the following tasks:

1. Prepare a series of overlay maps that show the natural resource characteristics and development features of the planning area. For example, show the forest cover type, soils, topography, ... transmission lines, recreation sites/trails, etc.

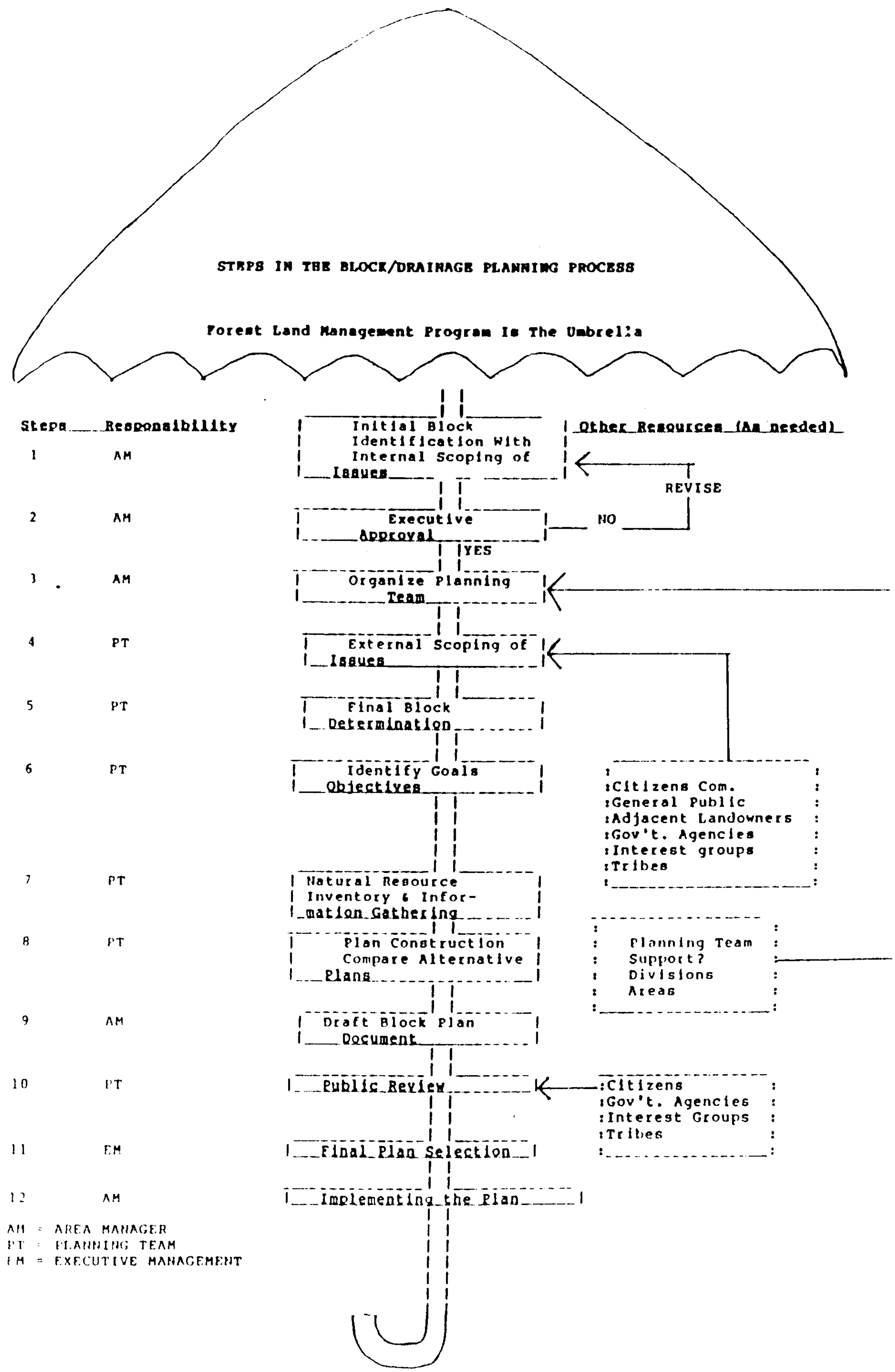

Figure 28. Flow Chart: Block Planning Process (Probst, 1987, p. 6)

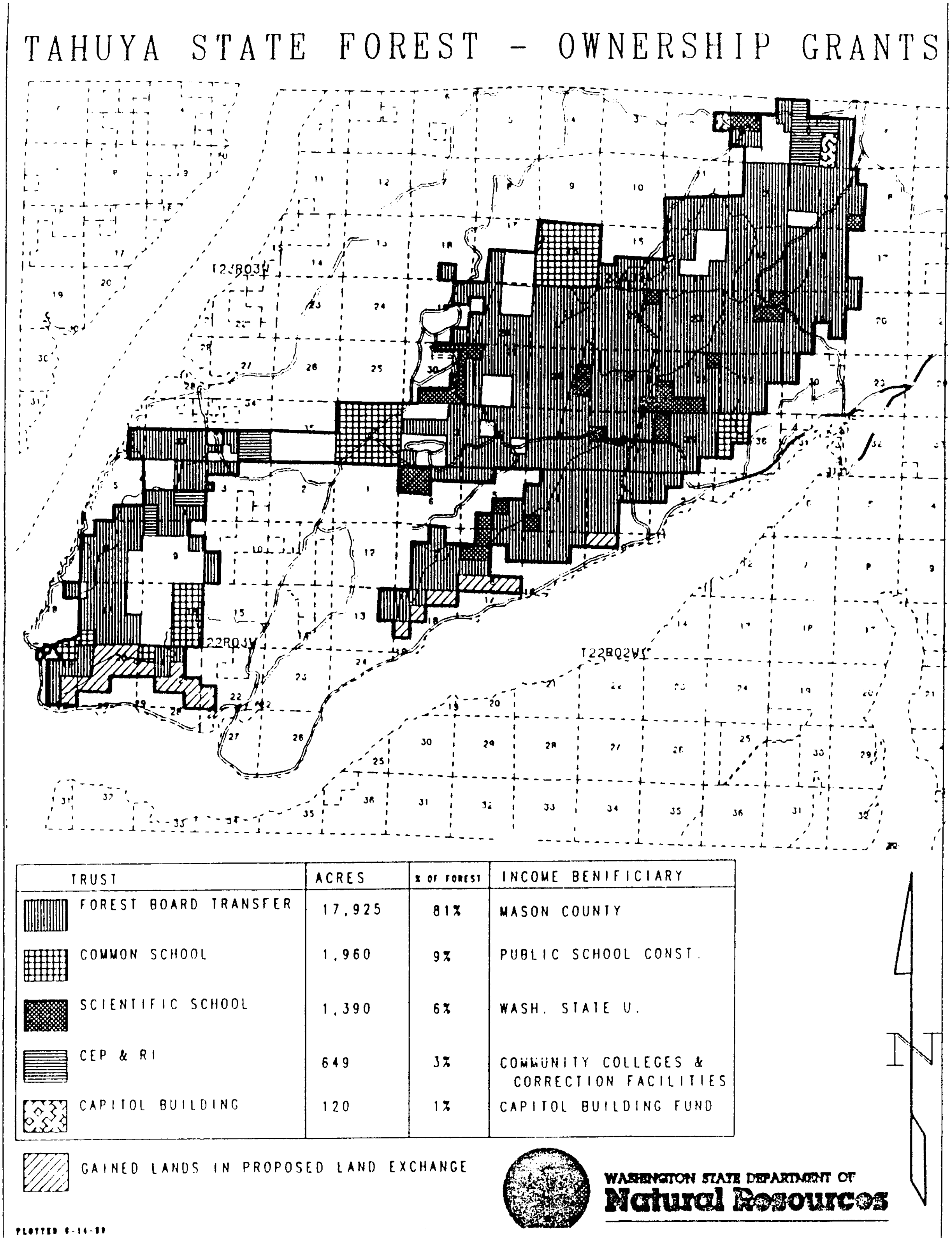

Figure 29. Sample Graphic: Ownership Grants
(Tahuya State Forest Management Plan, 1990, p. 13)

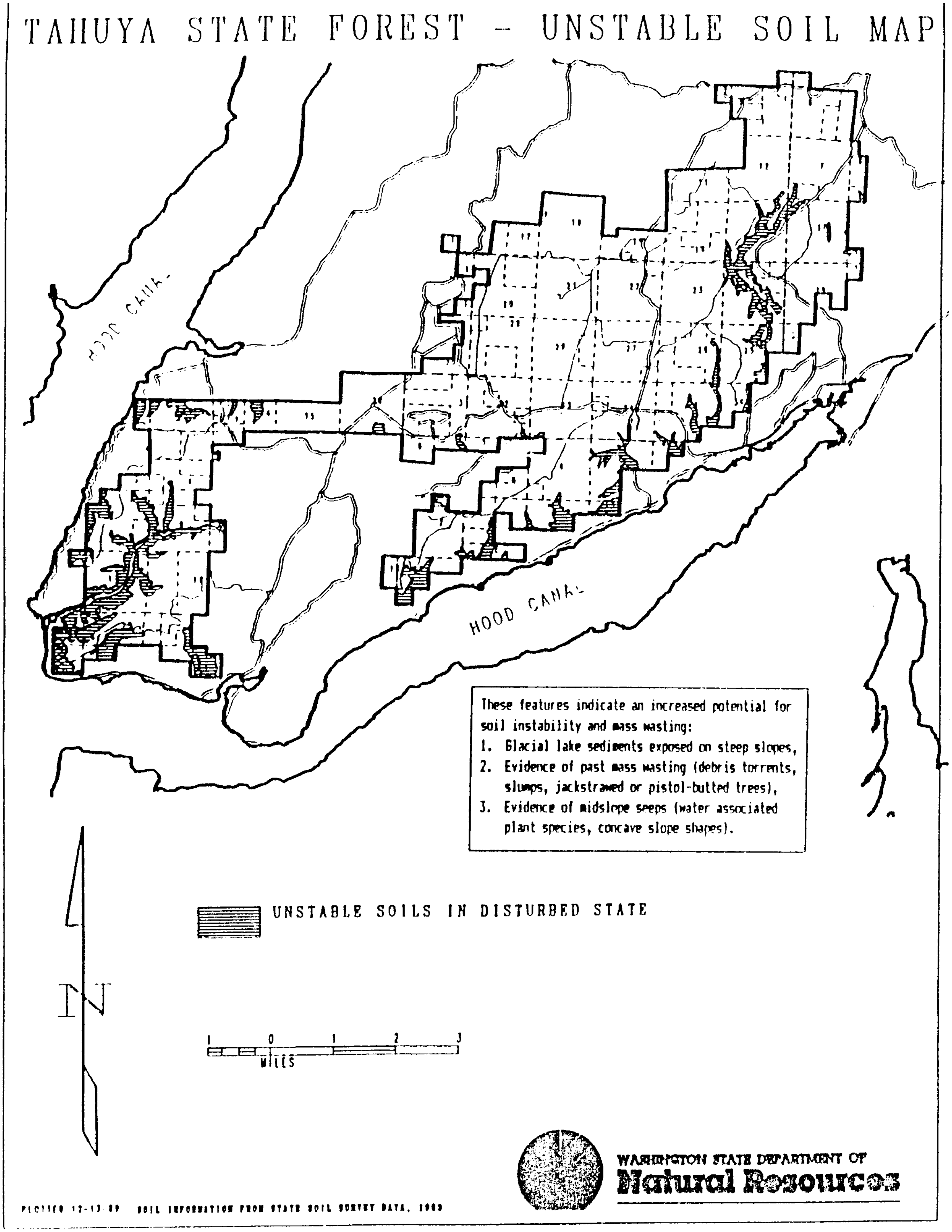

Figure 30. Sample Graphic: Unstable Soils
(Tahuya State Forest Management Plan, 1990, p. 54)

2. Prepare quantitative tables that show the resource distribution characteristics such as forest cover types by acre by drainage area.

3. Show the ten-year harvest schedule as an overlay on the resource features identified in task 1.

4. Show the proposed road network as an overlay on the resource features identified in task 1.

5. Integrate an overall riparian management zone plan that establishes fish and wildlife habitat goals and objectives for specific waters in the block.

6. Integrate a public use plan that shows the holding capacity of various recreation uses.

7. Other issues and concerns.

8. Integrate goals and objectives identified in step 6.

9. Develop a recommended plan with several alternatives that reflects [all of the above].

10. Plan selection by Area [Regional] Manager. (Probst, 1987, p. 18)

Step nine is to draft the document which explains the selected plan. Maps showing the proposed harvest and road plans are included. Figure 31 is an example of a block plan map. This document goes to executive management for review. Once approved, the document then goes to the public for review (step ten). Step eleven allows changes to the plan before its official adoption and implementation (step twelve).

3.2.3 Petri Net Representation

The block planning process, as represented by a petri net, is found in Figure 32. Figure 33 shows a portion of the corresponding petri net input/output matrix. Participants in each of the four block plans were interviewed. The petri net representation was constructed from the composite of information received in these interviews. Although each block plan possessed its own characteristics, the majority of steps are equivalent in each. The labels for the places and transitions of the petri net are:

CONDITIONS (STATES)

PI = Someone has identified an area with sensitive issues
P2 = A need exists for a block plan
P3 = GIS inventory database exists
P4 = GIS basemap data exists
P5 = Block area is defined
P6 = Executive Management (EM) has received block plan proposal
P7 = EM prepared for meeting

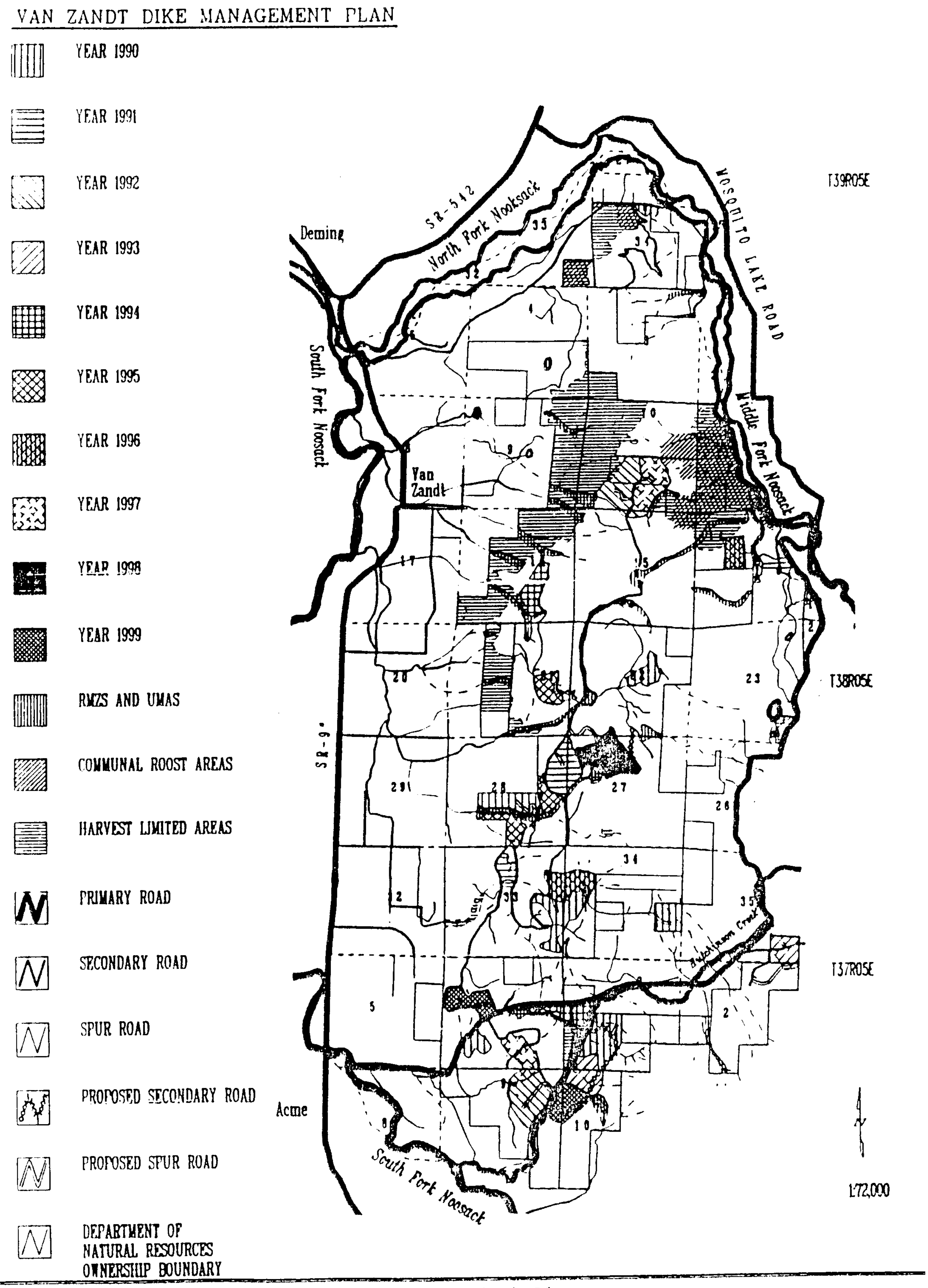

Figure 31. Sample Graphic: Block Plan
(Van Zandt Dike Block Plan, 1990, p. 60)

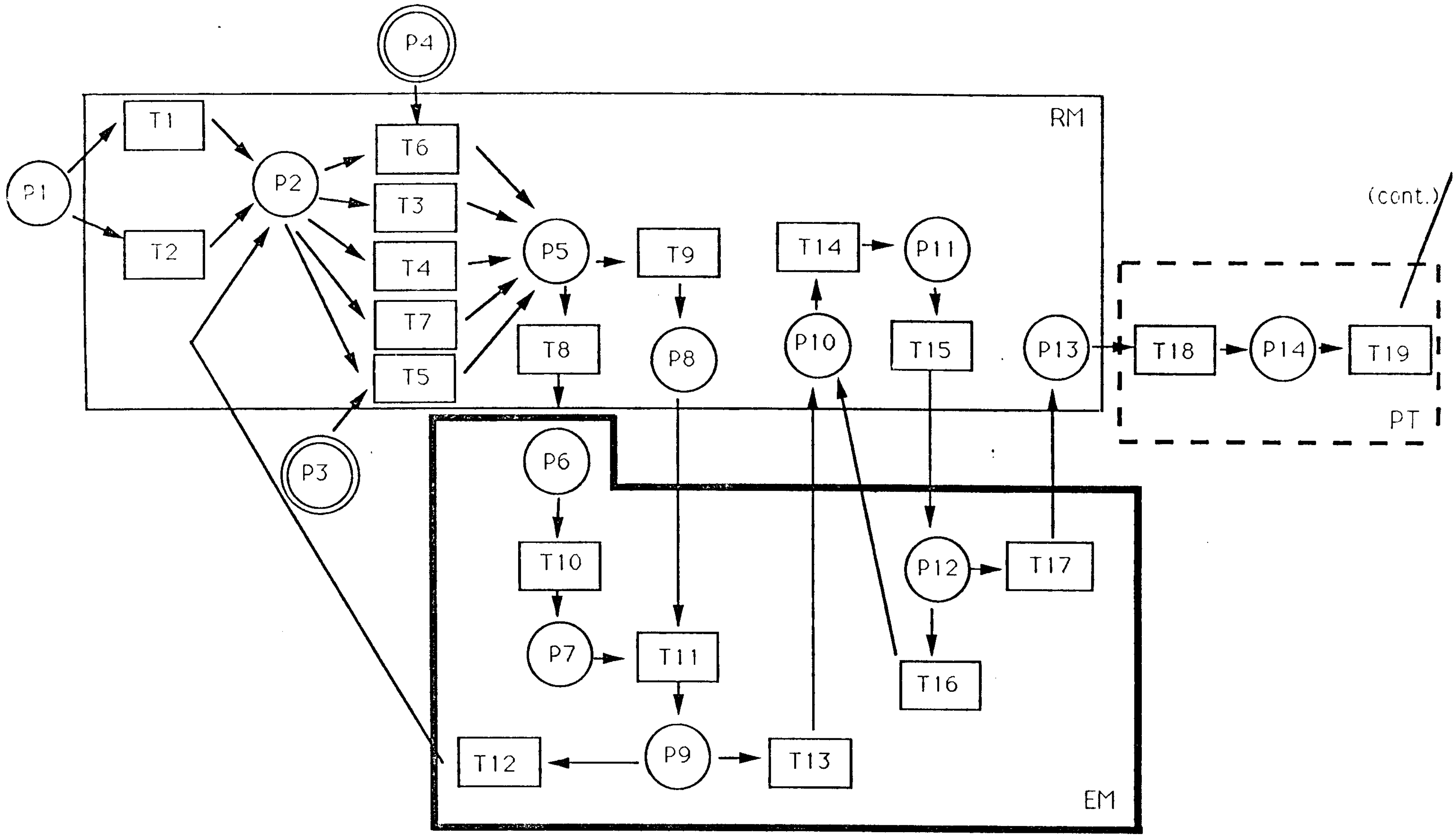

Figure 32.1 Petri Net: Block Planning Process

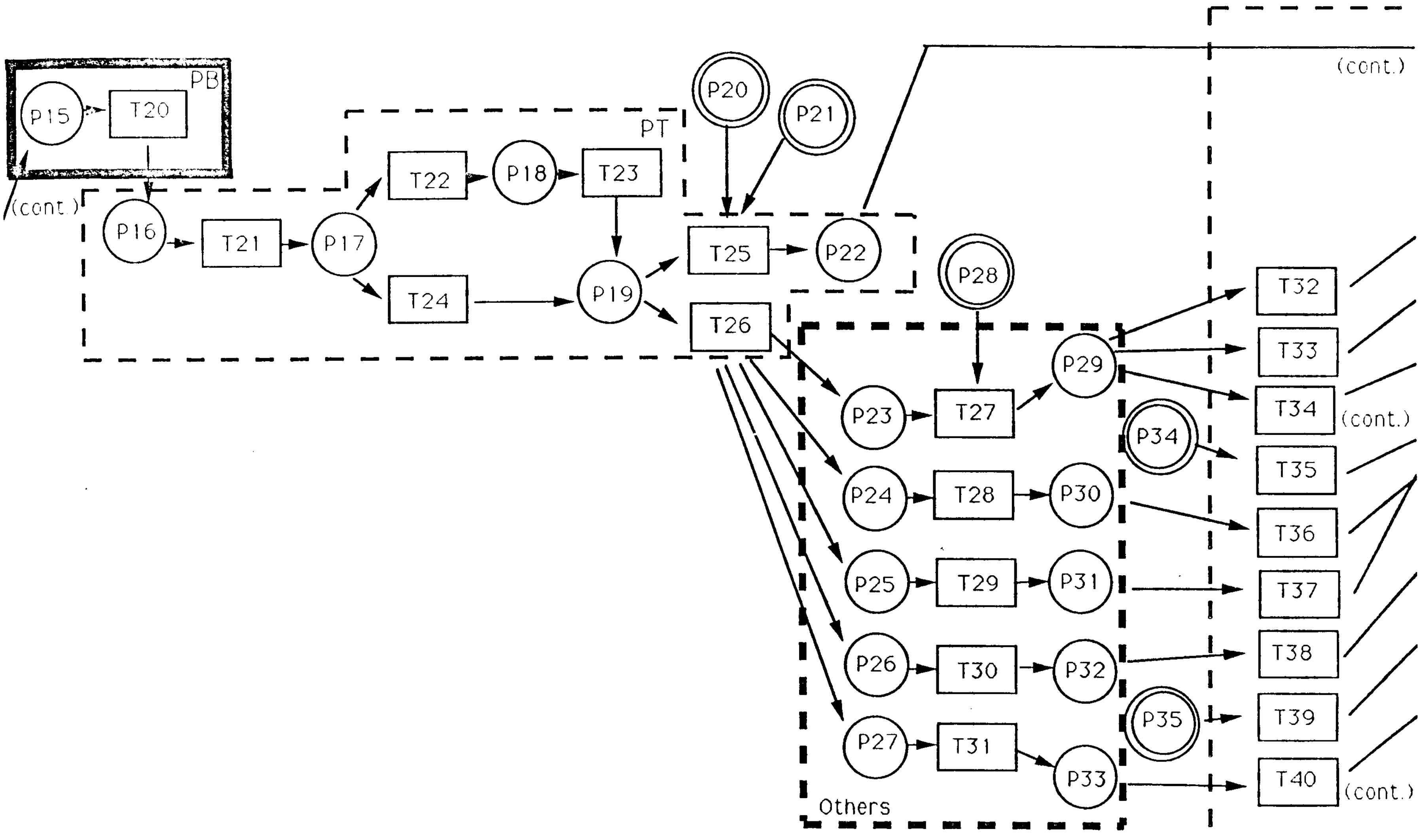

Figure 32.2 Petri Net: Block Planning Process

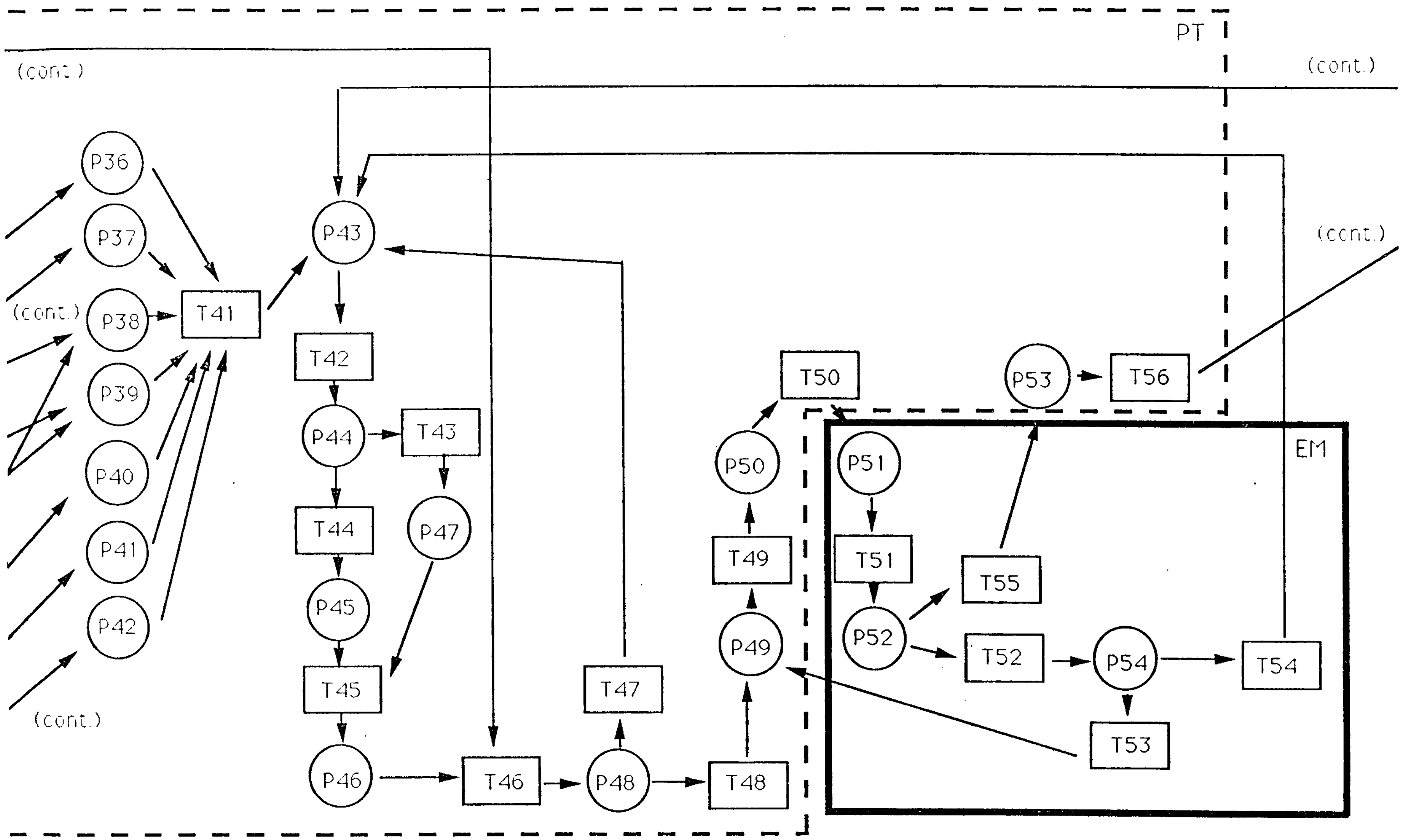

Figure 32.3 Petri Net: Block Planning Process

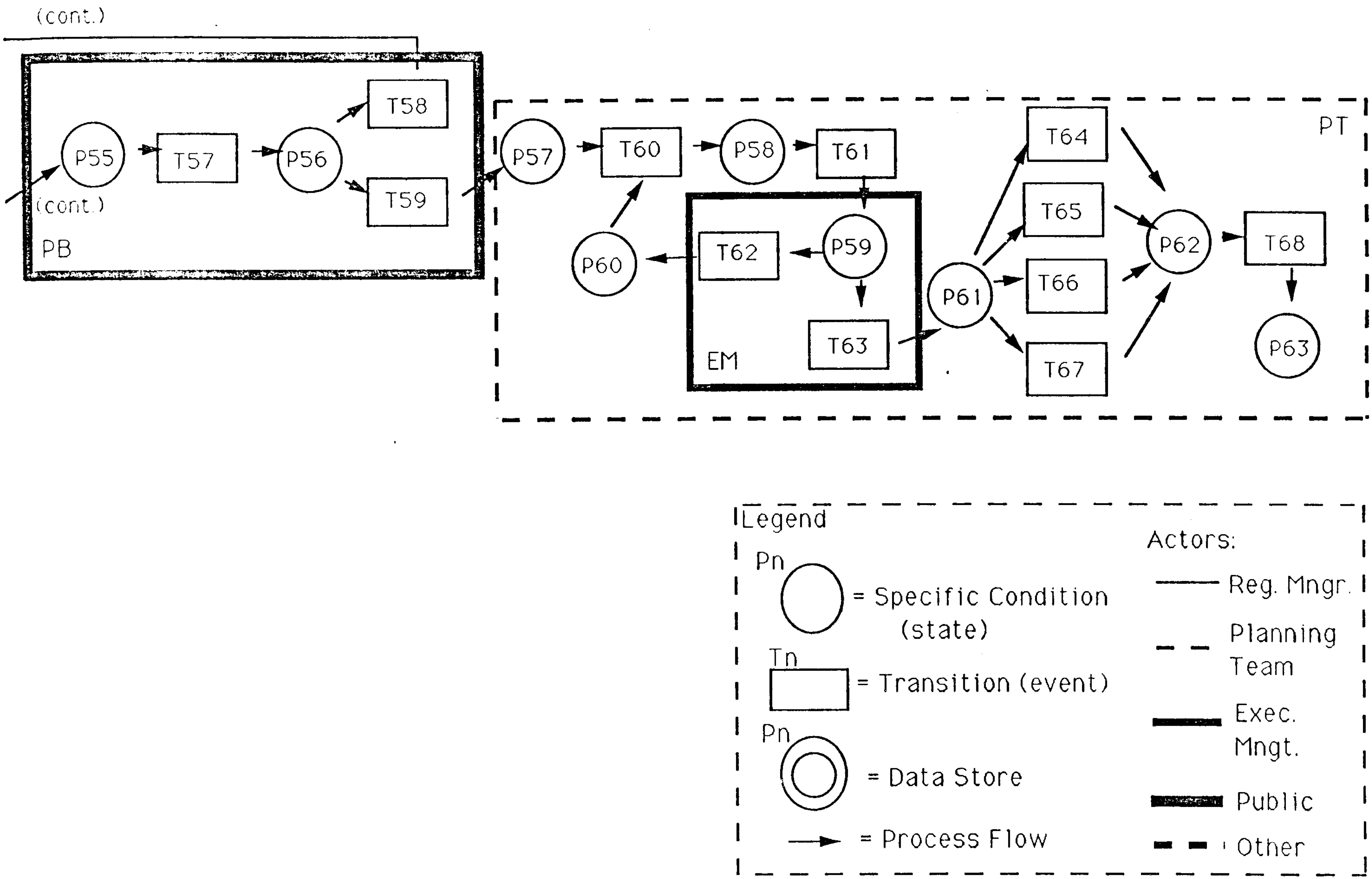

Figure 32.4 Petri Net: Block Planning Process

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29
T1	-1	1																											
T2	-1	1																											
T3		-1			1																								
T4		-1			1																								
T5		-1	-1		1																								
T6		-1		-1	1																								
T7		-1			1																								
T8					-1	1																							
T9					-1			1																					
T10						-1	1																						
T11							-1	-1	1																				
T12		1							-1																				
T13									-1	1																			
T14										-1	1																		
T15											-1	1																	
T16										1		-1																	
T17												-1	1																
T18													-1	1															
T19														-1	1														
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T25																			-1	-1	-1	1							
T26																			-1				1	1	1	1	1		
T27																							-1					-1	1
T28																								-1					
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T40																													
T41																													
T42																													
T43																													
T44																													
T45																													
T46																						-1							

Figure 33. Petri Net Matrix (partial): Block Planning Process

-1 = input to a transition
1 = output from a transition

P8 = Meeting is scheduled
P9 = EM ready to make final decision
P10 = Funding is approved/Ready to propose list of Planning Team (PT)
P11 = Proposed PT list exists
P12 = EM has received proposed PT list
P13 = PT participants have been approved
P14 = Workplan is complete
P15 = Public meeting has been scheduled
P16 = External scoping of issues is complete
P17 = External issues report is complete
P18 = Internal issues report is complete
P19 = Framework for block plan has been determined
P20 = Site-specific goals exist
P21 = Forest Land Management Program (FLMP) document exists
P22 = List of goals and objectives exists
P23 = GIS staff has received requests
P24 = Sustainable harvest calculations requests has been received at Forest Land Management (FLM)
P25 = Unit Forester (UF) has received request for new road proposal
P26 = Fish and Wildlife (F & W) has received request for Riparian Management Zone (RMZ) information
P27 = Other specialists have received information requests
P28 = GIS database exists
P29 = GIS products are complete
P30 = Sustainable harvest calculations are complete
P31 = New road proposal is complete
P32 = RMZ information is complete
P33 = Other information is complete
P34 = FLMP exists
P35 = Recreation Opportunity Spectrum (ROS) exists
P36 = Natural resource maps exist
P37 = Calculations of acres by cover type exist
P38 = Existing and proposed road network map exists
P39 = 10-year sustainable harvest schedule exists
P40 = RMZ plan exists
P41 = Public use plan exists
P42 = Information from other sources exists as needed
P43 = Ready to create a harvest plan for the block
P44 = Logging units have been delineated
P45 = Cut sequence has been developed
P46 = Effects are available for study
P47 = Logging units are in the GIS
P48 = Comparison of block plan and goals is complete
P49 = Ready to draft plan document
P50 = Block plan draft complete
P51 = EM has received block plan draft
P52 = EM has reviewed draft
P53 = PT has received approval from EM
P54 = Block plan draft has been rejected
P55 = Public has received block plan draft
P56 = Public has reviewed draft
P57 = PT has received approval from public

P58 = Plan is ready for final approval
P59 = EM has received final plan document
P60 = More fine-tuning is needed
P61 = Block plan has been given final approval
P62 = Plan is ready to be implemented
P63 = Plan has been implemented

Transitions (Events)	Actor*
T1 = Identify possible planning strategy	RM
T2 = Brainstorm issues	RM
T3 = Prepare map of proposed block plan area	RM
T4 = Prepare paper explaining need for block plan	RM
T5 = Determine acreage and inventory	RM
T6 = Delineate block plan area	RM
T7 = Estimate finances needed to prepare plan	RM
T8 = Send block plan proposal to EM	RM
T9 = Schedule meeting for PT and EM	RM
T10 = EM review proposal	EM
T11 = Meeting occurs	EM/RM
T12 = EM rejects proposal	EM
T13 = EM approves funding for proposal	EM
T14 = Develop list of proposed PT participants	RM
T15 = Give PT list to EM for approval	RM
T16 = EM rejects PT list	EM
T17 = EM approves PT list	EM
T18 = Develop work plan	PT
T19 = Schedule and advertise public meeting	PT
T20 = Meeting occurs	PT/PB
T21 = Prepare report from public meeting	PT
T22 = Complete list of internal (from within DNR) issues	PT
T23 = Consolidate issues reports	PT
T24 = Refine block plan boundary map	PT
T25 = Identify goals and objectives for block plan	PT
T26 = Request maps/information as needed for all issues	PT
T27 = Prepare GIS products	GIS
T28 = Run sustainable yield model	FLM
T29 = Prepare new road proposal map	UF
T30 = Prepare RMZ information	FW
T31 = Prepare other information	--
T32 = Receive natural resource maps from GIS staff	PT
T33 = Receive inventory calculations from GIS staff	PT
T34 = Receive existing road maps from GIS staff	PT
T35 = Receive 10-year harvest plan from FLMP manual	PT
T36 = Receive sustainable harvest calcs. from FLM staff	PT
T37 = Receive proposed road information from Unit Forester	PT
T38 = Receive RMZ information from F & W staff	PT
T39 = Receive public use plan from ROS document	PT

T40 =	Receive other information as needed	PT
T41 =	Combine all information to begin planning	PT
T42 =	Delineate logging units (harvest units)	PT
T43 =	Digitize unit boundaries into GIS	GIS
T44 =	Decide sequence of cuts	PT
T45 =	Enter sequence of cuts into GIS and "pseudo-simulate" effects of next three 10-year cuts	GIS
T46 =	Compare simulated effects to goals and objectives	PT
T47 =	Realize block plan need to be re-worked	PT
T48 =	Realize block plan meets goals and objectives	PT
T49 =	Draft plan document and maps	PT
T50 =	Give draft to EM	PT
T51 =	EM reviews draft	EM
T52 =	EM rejects draft	EM
T53 =	Decide minor changes are needed in draft	EM
T54 =	Decide major changes are needed in plan	EM
T55 =	EM approves draft	EM
T56 =	Circulate draft for public approval	PT
T57 =	Public reviews draft	PB
T58 =	Public finds major areas of concern	PB
T59 =	Public finds no areas of concern	PB
T60 =	Fine-tune plan document	PT
T61 =	Give final document to EM	PT
T62 =	EM rejects final document	EM
T63 =	EM approves final document	EM
T64 =	Develop budget	PT
T65 =	Develop annual work plan	PT
T66 =	Develop specific 10-year action plan	PT
T67 =	Develop monitoring plan	PT
T68 =	Implement plan	PT

*EM = Executive Management
FLM = Forest Land Management Staff
FW = Fish and Wildlife Departments Staff
GIS = GIS staff
PT = Planning Team
PB = Public
RM = Regional Manager (this title has replaced Area Manager)
UF = Unit Forester (or District Manager)

Four major actors were defined in the petri net (see legend): the regional manager who initiates the block planning process, the planning team appointed to develop the plan, executive management responsible for final approval of the plan, and the public that is asked for input. Other actors involved as supporting groups include the GIS staff, the Forest Land Management staff, and representatives of the Fish and Wildlife Departments. Other specialists are involved depending on the issues.

As in the previous decision-making task, a more detailed level of representation is shown by the petri net in Figure 32 than by the flow chart in Figure 28. In particular, the feedback loops representing approval or rejection between various steps were required to complete the petri net representation. For example, the condition of needing to create a harvest plan (P43) can be assigned a token by four different events: the initial planning stage has been reached (T41), the planning team rejects the proposed plan (T47), executive management rejects the plan (T54), or the public rejects the plan (T58). Other feedback loops are initiated at T12, T16, and T62. Other details added include a monitoring condition at PI, and the interfaces with other staff for necessary information (P23 - P27).

The GIS has been used to simulate the cut sequence (T43 and T45) in only one block plan. Previous block planning did not include a "simulation" of the future. The word "pseudo-simulation" is used since the simulation is not performed automatically. Instead, the current inventory is shown first in map form. Then the list of units to be cut are entered into the database to "update" the inventory. A second map is created to show the status of the inventory as it would appear after ten years. The process is repeated for two additional ten-year harvesting periods.

More detail is still needed for the actual planning process (P43-P46). This part of the process is, for the most part, performed as a mental exercise, using mapped information only for reference. A process for weighing the alternatives was documented. However, it was very difficult to obtain detailed information on how the interviewees developed the alternative plans as a mental process. There is still a lack of ability to document how the human mind simultaneously compares a set of issues and creates alternative solutions to the problem at hand. More detail is needed on the iteration between the various issues. One can establish if the issues are prioritized or of equal weight. But what is still not well understood is how the forester uses his/her experience as well as new information to examine the issues and objectives to generate a "first-cut" harvest plan.

3.2.4 Benefits of Geographic Information and Analysis

Three benefits of geographic information and analysis were documented during the interviews. Although qualitative, they are included here to complete the discussion of the block planning process.

Benefit: Credibility with Public.

The ability to produce maps showing all areas of sensitive issues is viewed favorably by the public. The fact that these maps are at the same scale (and therefore, comparable) and of good visual quality extends an air of technological capability of the DNR. Having all issues mapped and displayed at the public meetings shows that the DNR realizes the special issues and is following a systematic procedure to arrive at a mutually acceptable solution. Before the public was included in the planning process, public opposition was often given when a harvest contract was circulated for bids. Often, the opposition led to time consuming litigation. If public concerns are raised, the harvest plan needs to be re-designed. At one time, up to 20% of the plans needed to be re-designed. At present, less than 5% meet with public concern. It must be noted that only a proportion of the increased success rate, and subsequent time savings, is attributable to the use of geographic information and analysis in the block planning process. Other factors include the ability to document the orderly planning process and the act of including the public early in the process (Olsen, et. al., 1990).

Benefit: Improved knowledge of areas of concern before on-site activity begins.

The ability to map the various issues of the area allows the forester to plan a more efficient harvest. Knowing if there are recreation trails or erodible soils in the area before the on-site activity begins is a time-saving benefit. Prior knowledge of recreation trails allows sufficient time to notify the public of a trial closing and to plan an alternate trail. Knowing where the osprey nest is before road construction begins will save both time and money. If the information were not available during the planning stage, many of these issues would be dealt with on an ad hoc basis as they are confronted after harvesting has commenced (Poch, 1990).

Benefit: Ability to perform a more "complete" alternative study.

The ability to produce maps of the various areas of concern allows more information to be used in the generation of alternatives. Without these maps, the alternatives would be generated only from experience and minimal, costly on-site inspections. Use of the GIS to simulate the effects of a particular cut sequence facilitates long-term planning. Once a number of alternatives have been generated, the GIS can be used to evaluate the plans in respect to site-specific objectives. The GIS will especially be useful in evaluating the cumulative effects of harvesting across an entire block and region.

3.3 Old Growth Commission Task Force

3.3.1 Background

The Old Growth Commission Task Force was a committee of 32 citizens representing various interest groups surrounding the issues of harvesting the old growth forests in the Olympic Region. The old growth forests needed to be harvested to continue revenue flows to trust beneficiaries because revenues from certain tracts of lands are earmarked for specific state institutions such as the agricultural university, the state university, normal schools, and penal institutions. If harvesting was deferred entirely on these tracts, the institutions would lose a substantial portion of income. Cutting the old growth forests, however, has an adverse affect on ecological diversity, availability of wildlife habitats (especially for rare and threatened species such as the Spotted Owl), and the preservation of original forest cover for aesthetic, recreational, and spiritual values (Commission on Old Growth - Final Report, 1989). The Task Force goal was to create a harvest plan which could be agreed upon by all participants.

3.3.2 The Decision-Making Process

The decision making in this task involved negotiations between the various interest groups. The first step in this process was to ascertain the present status of old growth stands. This was accomplished by creating a map from the GIS inventory database showing all mature (i.e., old growth) stands. These stands covered 65,000 acres.

Products of the GIS were used for problem identification (Figure 34 is an example of one of the products). Mapped information showed the location of the old growth forests, ownership types, rivers and roads, sensitive cedar bogs, winter forage areas for elk, known Spotted Owl locations, and riparian management zones. The maps were used to discuss the various issues and show spatially how each issue was affected by the harvest of old growth forests. The other information used in the problem identification stage was the sustainable harvest yield calculations for the various trust beneficiaries of old growth land holdings. This information was used to show the impact of a deferred harvest on the revenues for the beneficiaries and on the local timber market.

The first decision made was to set aside 15,000 acres of old growth forest to be deferred from harvest for at least 15 years. The only information available on the choice of these figures was that several acreage figures were proposed and 15,000 was chosen as the best balance between deferring harvest on all old growth stands or on none. The remainder of the Task Force discussions were spent deciding "which" 15,000 acres to set aside. A first alternative was chosen arbitrarily. Maps were used to identify the effects of this solution on trust beneficiary revenue, road management, land trades, diversity and complexity of species, future timber sales, the Spotted Owl nesting sites, fishing rivers, riparian management zones, and elk forage. The placement of the 15,000 acres was altered until a solution was agreed upon by all participants. Again, no detailed information was available on how the effects on sensitive issues were identified. It seems that the primary effect studied was changes to the volume of cuts for each trust for the next six five-year periods under each proposed alternative. Information on negotiation processes is not easily collected because in a committee setting, numerous interactions occur between the negotiators and these interactions are not easily documented ’after the fact.’

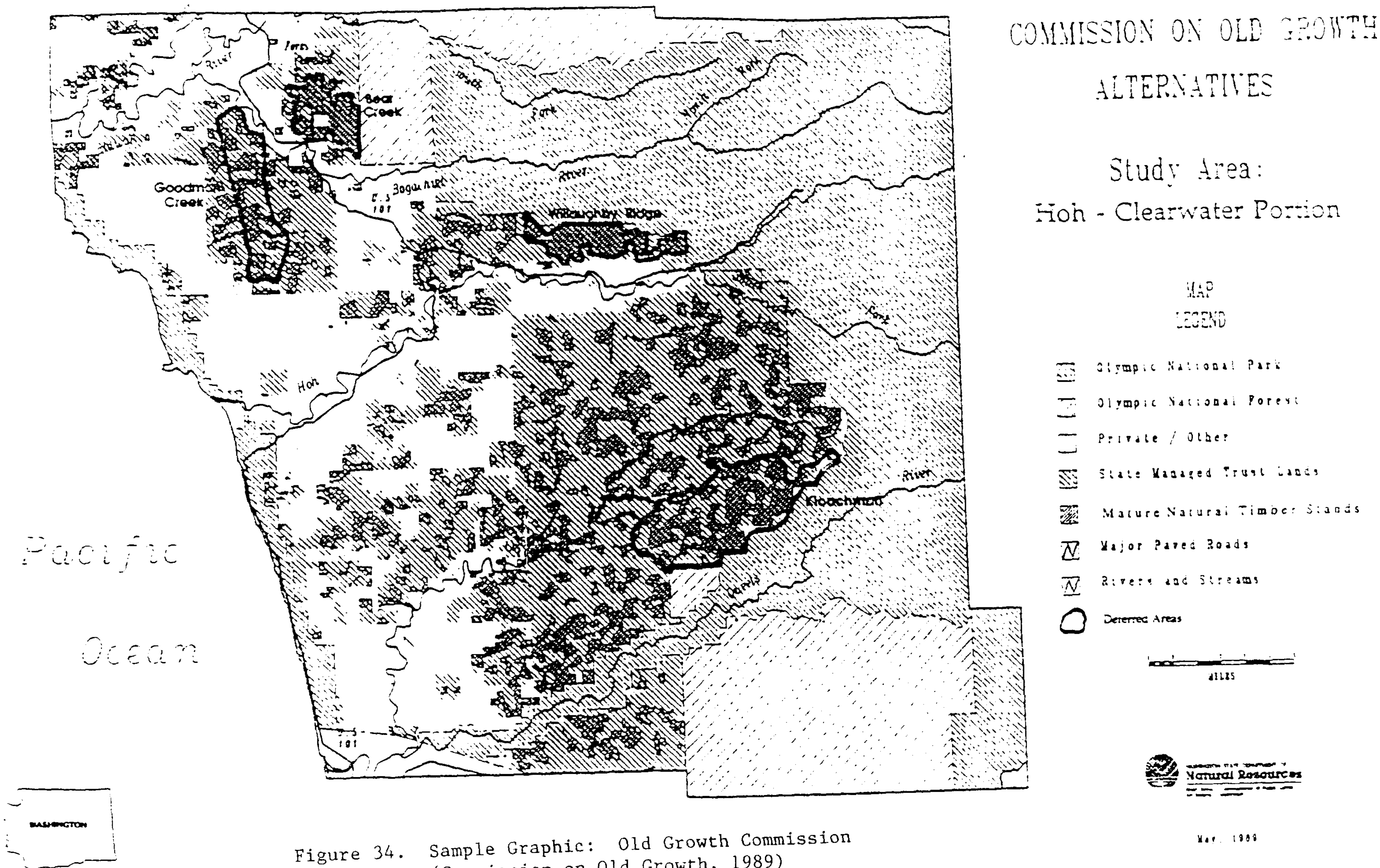


Figure 34. Sample Graphic: Old Growth Commission
(Commission on Old Growth, 1989)

3.3.3 Petri Net Representation

Since detailed information was not available for this task, a petri net was not constructed. The lack of detail may be due to a lack of ability to document how group decision making is performed, and especially, how negotiations are actually performed. A structure is needed to support the collection of such information. Perhaps minutes of the meeting could be collected and comments evaluated to identify the progression of mental activities toward consensus. Another possibility may involve the researcher observing the negotiations as they occur. The shaded portions of Figure 35 (an adaptation of Figure 1) show those steps which could not be documented in this decision-making process.

3.3.4 Benefits of Geographic Information and Analysis

The benefits of geographic information use described during the interviews were of a qualitative nature. They are reported here to complete the decision making example. GIS products were used from the first meeting to the last meeting of the Task Force (Yeary, 1990). Initially, the maps were used to orient the group to the topography of the Olympic Region and to show the locati on of old growth stands. The various maps facilitated the process of problem identification by allowing all of the issues to be shown in a geographical context. The maps were overlaid to show relationships between various issues. For example, some maps showed where old growth trees would have. to be left to protect the riparian management zones and known Spotted Owl nesting sites. The maps forced discussants to adopt a more rational view towards a mutually acceptable solution rather than basing their discussions on purely emotional viewpoints (Gorman, 1990). Furthermore, the maps facilitated the discussions so that negotiations were performed in an efficient time frame. If the map products had not been available during the discussions, it is probable that a mutually acceptable decision on where the 15,000 acres should be set aside would not have been reached (Yeary, 1990).

3.4 Fire History Mapping.

3.4.1 Background

The Fire Control Division of the DNR provides fire control for the land managed by the DNR and for all private forested lands. Because urban areas continue to spread, the probability of a wildfire invading a residential area, or a house fire moving into a forested area, continues to increase. The DNR is responsible for any fire that starts on state protected land. The annual budget for fire control is approximately $ 9.9 million. Of this amount, about 62% comes from state funds. These are funds voted on by state legislature and are in competition with other funding needs such as education and health institutions. Federal monies account for 5% of the annual budget. The remaining 33% comes from fees paid by forest land owners. This includes any land holdings that contain forest fire fuel (i.e., trees). Almost all land owners west of the Cascades fall into this category (except for areas well within an urban area). This fee is set by state law (Boyes, 1990).

In past years, the fee had been set at $ .21 per acre owned or a minimum payment of $ 5.60. A problem exists at the urban-wildland transition zone where so many of the ownerships are small acreages (less than 25 acres). Over 50% of the fire suppression activities per year are required on these small acreages. Yet, these land owners are paying a much lower proportion of the required funding. A need existed to alter the assessment of the forest suppression fee. The fire history map was a GIS product created to support this need.

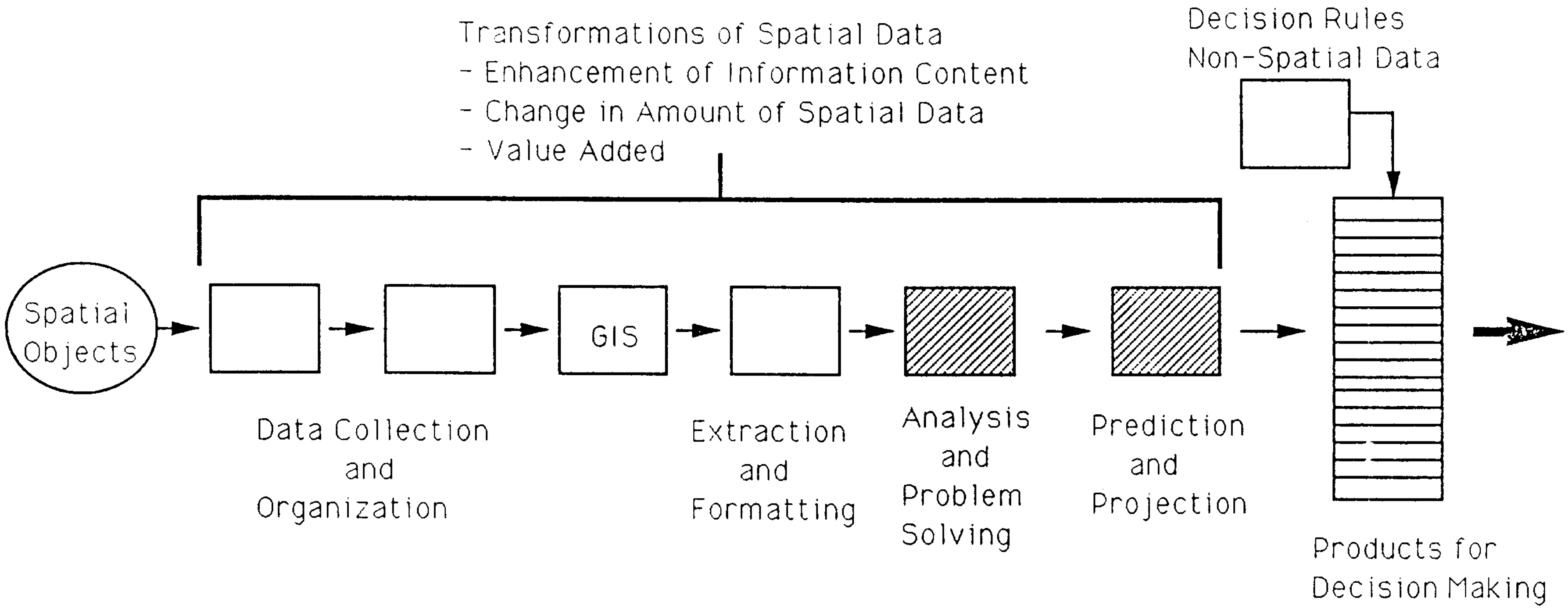


Figure 35. Undocumented Steps in the Decision-Making Process (after Calkins, 1989)

3.4.2 The Decision-Making Process

The fire history map showed the occurrences of fires across the state of Washington between 1978 and 1987. The location of fires is recorded by section number, so each section was shaded according to the number of occurrences in that particular section (I fire, 2 to 3 fires, or 4 or more fires). By adding other basemap information such as cities, roads, and rivers, the map became a visual representation of where the fires occurred in relation to the residential communities.

Two audiences viewed this map. One group was the legislative representatives of various areas. They were able to visualize their area and see the amount of fire control that had been required in the past. The second audience was comprised of the Washington Farm Forestry Association (WFFA) and the Washington Forest Protection Agency (WFPA). The first group includes the smaller land owners (less than 1000 acres with a non-industrial land use) and the second group includes the larger land owners (greater than 1000 acres, generally with an industrial forestry land use). After viewing the map, the two groups could no longer dispute the fact that an imbalance existed between the amount of fee paid and amount of fire control required on the smaller land parcels. Having won the support (or at least agreement) of the WFFA and WFPA, the legislature was approached with a request to increase the minimum fee assessment for small land owners and slightly increase the per acre fee also. In 1989, legislation passed an increase to $ .22 per acre or a minimum of $ 10 per land holding.

3.4.3 Petri Net Representation

This task was chosen primarily because it involved decision makers outside the DNR agency. Although a significant decision-making process, its extension beyond the bounds of the agency complicated the already difficult data collection process. Decision makers outside the DNR agency were unavailable for interviews. Therefore, no petri net representation was completed for this task.

3.4.4 Benefits of Geographic Information and Analysis

One benefit was documented during the interview process. This particular benefit can be quantified by using the economic method of expected profit calculation.

Benefit: Increase in Funding

This benefit is derived from being able to represent the existing problem to the WFFA in a map form. By gaining the support of this group, the chance of legislation being passed was increased. (In 1987, the same request had been rejected.) While other factors may have influenced the decision, the interviewee estimated that without the map product, the probability of legislation being passed was .85, having the map product available probably increased that probability to .99. The total increase in funding will amount to S 1.5 million over a two-year period. Calculating this as an expected profit:
$ 1.5 million X (.99) - $ 1.5 million X (.85)
provides a benefit of $ 210,000.

4. Conclusion

The previous section showed that petri nets could be used to represent decision-making processes using geographic information. However, the petri net does require a very detailed understanding of the entire decision-making process. The next chapter will discuss how measures of costs and benefits may be attached to a petri net representation.

Chapter 5. Extensions to the Petri Net Model

1. Introduction

In the previous chapter, it was shown that petri nets were able to model the use of geographic information and analysis in decision making as long as a sufficient level of detail was available for each step in the process. Three specific types of tokens will be presented in this chapter. This chapter will discuss how measures of costs and benefits could be attached to the model. The discussion will be conceptual, since data on these measures is unavailable at the level required for actual analysis. Specifications, however, for the data to be collected will be presented.

2. Petri Net Tokens

As discussed in Chapter 3, colored petri nets allow tokens to represent various entities in the system. Entities include any component of the system that has been defined. Thus, an entity can be a tangible object such as a map product, an intangible object such as cpu consumption, or a value such as the number of maps to produce. Through simulation, tokens can be used to represent the flow of entities through the system. Because different token types can be added to a petri net, firing rules must be specified for each transition. The firing rules are generally shown in matrix form. Therefore, a colored petri net will require at least two types of matrices: (1) the general input/output matrix which defines the relationships between all places and all transitions, and (2) firing rule matrices for each transition which define the possible combinations of required inputs and the corresponding outputs for each combination of inputs. (Examples of firing rule matrices are shown in Figure 17 for the disk allocation algorithm.)

For this research, three additional types of tokens are defined: tangible object tokens, counter tokens, and resource measurement tokens. The first type of token represents various tangible objects flowing through the system (e.g., survey forms, present net worth calculations, and names of stands). These tokens would show specifically in what processes these different objects are used. Figure 36 shows the use of a token to represent the survey form used in the PCT funding allocation process. The token representing the survey form is initially available at P3 (having been created by some transition outside the modeled system). This token is carried through transitions T3 and T4, and then used in transition T5 (fill out survey forms). During transition T5, the original token is replaced by a different token representing the completed survey form. This token is carried through transition T15 and used again in transition T16 (enter survey data into GIS inventory database). Since this last transition transforms the survey form information into the GIS inventory database, the token representing the survey form is not carried beyond T16.

The second type of token represents counters for the various objects flowing through the system. Figure 37 shows a counter token representing how many stands require PCT prescriptions and sketch maps. Each Lime transition T27 fires, one token is removed from P27. Transition T27 will be enabled (i.e., continue to fire) as long as tokens exist in P27. In this way, the counter token simulates the iterative looping of a particular sequence of transitions based on some condition.

A third type of token, required to meet the objectives of this research, is a measurement token for various resources in the system. These will be termed "resource measurement tokens" for the remainder of this discussion and will have numerical values. Appropriate resource measures include the costs of each event (transition) and the benefits associated with each condition (place) that is created by the occurrence of an event. Probable measures for costs include time costs such as person-hours or Lime losses, and resource expenditures such as cpu consumption or spent dollars; measures for benefits include time savings such as person-hours, cost savings in dollars, or percentage decrease in uncertainty.

Resource measures are shown in graphic form as a function next to each place and transition (Figure 38). Each resource measurement unit can be viewed as a global variable in a computer program. As transitions fire and conditions are met, the values assigned to these variables are altered. Figure 39 shows how the functions are represented in matrix form. Each row represents a unique measurement unit, while columns represent places and transitions. Functions are specified for each appropriate transition and place. No functional entries exist if a place or transition does not alter a measurement. As the petri net is simulated, the additions and subtractions to these measurements are governed by this matrix. A total value for each measurement (i.e., for each row) can be computed at the end of a simulation run. However, the different units may not be additive for each transition or place (i.e., for each column). The units would be additive only if each can be converted to a common unit of measure.

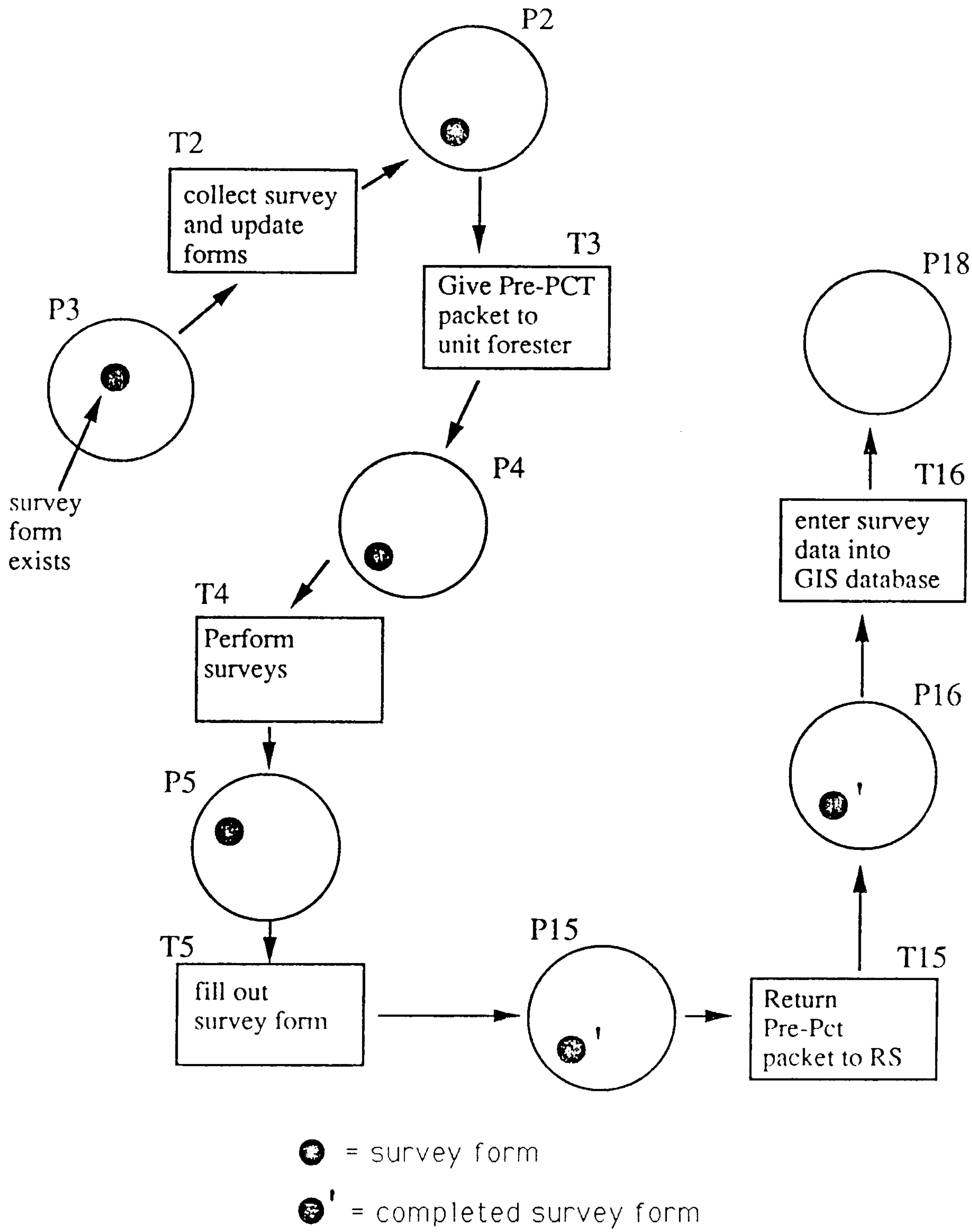


Figure 36. Tangible Object Token

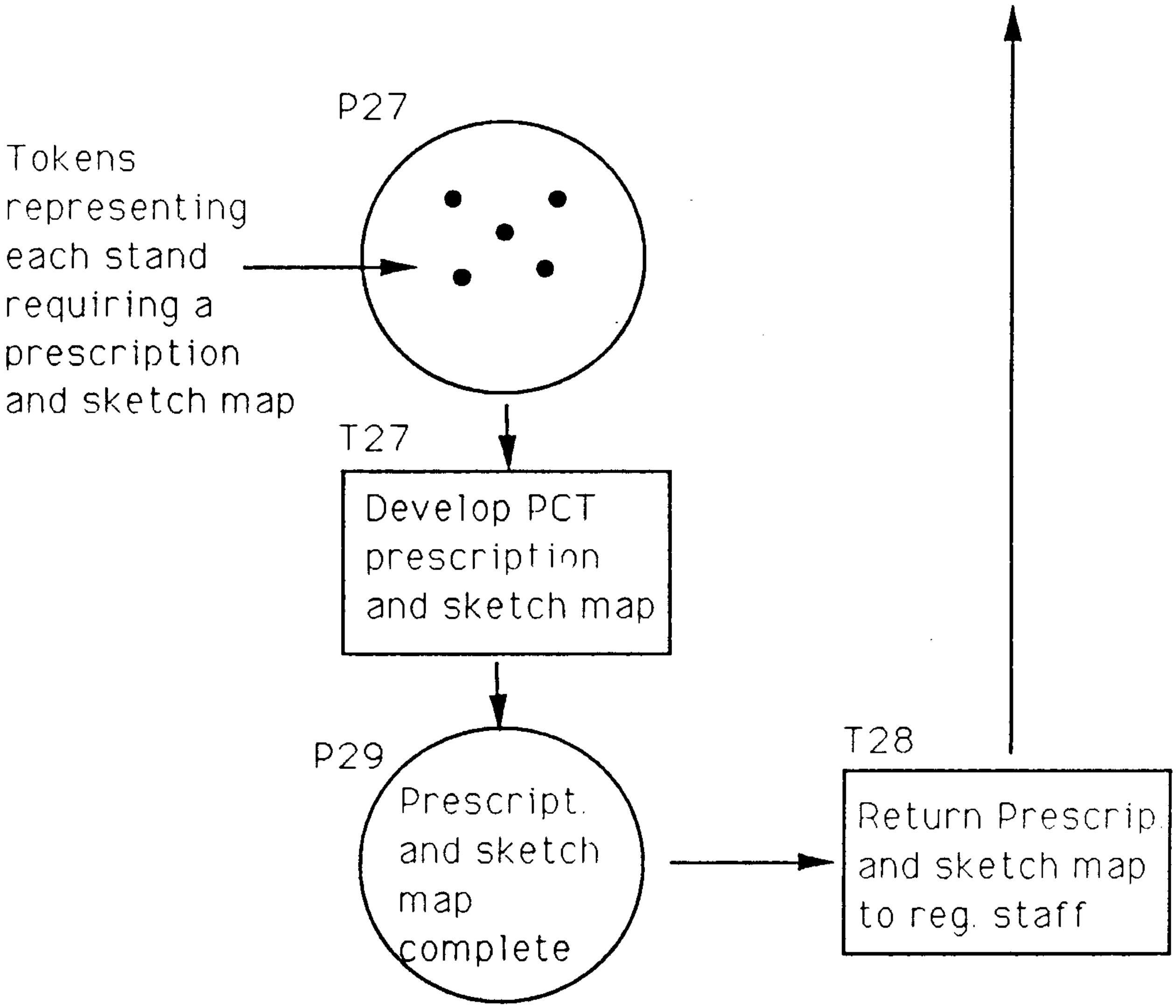


Figure 37. Counter Tokens

3. Collecting the Information for Tokens

Once the detailed level of information required for the construction of the petri net is available, the next step is to acquire information to incorporate the various types of tokens into the model. For example, the next questions pertaining to the token representing a survey form may be "Who actually creates the survey forms?" and "What happens to the actual form after the data is entered into the GIS?" It is felt that the level of detail provided in the petri net representation aids the interviewer in asking the right questions and allows the interviewee to answer the question as it directly relates to the model in front of them. Information needed to incorporate counter tokens includes the condition(s) which require repetitive tasks and possible limits to the number of times processes can be repeated.

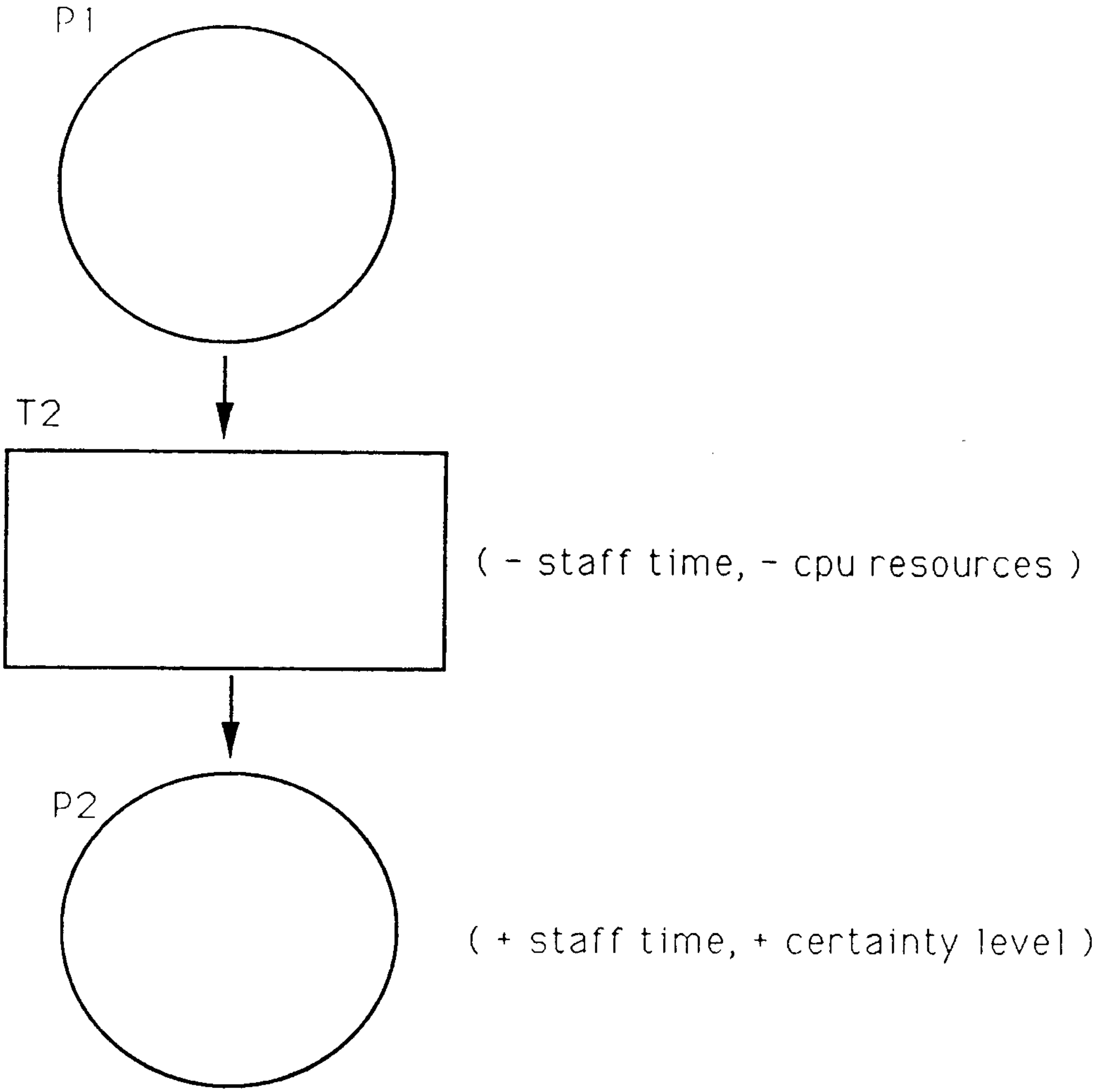
Collecting the information required for the use of "resource measurement tokens" will not be an easy task. While detailed records of costs may exist, record of benefits associated with each step of a particular decision-making task are not known to exist at present case study sites. Cost measurements in terms of time could be collected by asking "how long does it take to do each step?" The answer should be given in two forms: the time frame allowed for the event to occur, and the time required to perform the task. For example, it may take only 12 hours of intensive discussion to approve a plan, but the approval process requires a time frame of at least one month. Then, the time actually expended on this event would be one month.

Generally, the time required to perform a task is reported as an estimate. However, if computers are used to perform specific tasks, automatic logging programs can record the amount of real time and cpu time spent performing each task. This recording is being done at an aggregate level at the Olympia, Washington site. Users of the GIS are required to enter a "program number" when logging onto the system. This number specifies to which program the connect time should be billed. The programs are divided into various decision-making tasks. For example, records differentiate between computer time spent in support of precommercial thinning or stand reforestation, but do not differentiate between the steps identified for the precommercial thinning decision process. It would be possible to record information at this higher level of detail if the decision process was decomposed into the various steps and "task numbers" defined for each.

Collecting information on benefits associated with each resulting condition will be even more difficult. Decision makers do not generally think in terms of benefits associated with reaching a particular step in the process. Perhaps the "value added" concept will need to be introduced during the data collection process. A question such as, "What is it worth to the decision maker to have this particular piece of information available at this point in the process?" could be asked.

4. Conclusion

It was shown in the preceding chapter that petri nets can be used to model decision-making processes. This chapter has discussed how colored tokens can be used to represent objects and resources that flow through the system. The concept of a "resource measurement token" has been introduced as a means for calculating the overall costs and benefits associated with each step in a decision-making process. The information required to use colored tokens in a petri net increases the level of detail required in a "use of geographic information" study. However, it is felt that the costs involved in data collection will be outweighed by the benefits of allowing a decision-making process to be represented in a very structured method. Once the measurements of costs and benefits are available, colored petri nets allow these measures to be attached to each step in the process and to the process as a whole.



Costs measurement at transitions
Benefits measurement at places

Figure 38. Functions for Measurement Tokens

	T1	T2	P1	P2	Total
Staff Time (hours)	-20	-5	+10	+25	+10
CPU Resource (minutes)	-640	-5			-645
Certainty			+ .03	+ .10	+ .13

Figure 39. Functions for Measurements Tokens (in Matrix Form)

Chapter 6. Conclusions and Further Work

1. Conclusions

The objective of this research is to demonstrate (through an in-depth case study) that the use of geographic information and its analysis can be modeled in sufficient detail to permit the identification of costs and benefits attached to all or part of the decision-making process.

An initial assumption of this research was that a better understanding of the "use" process would support one of the following:

- the identification of methods for establishing the value of information that will apply to the value of geographic information;

- the identification of necessary modifications to these evaluation methods;

- the determination that even more information is needed before we are able to determine the costs and benefits of geographic information use in decision making.

The conclusion supported by this research is the third choice: more information is required to determine the costs and benefits of geographic information use in decision making. It has also been concluded that petri nets are able to model some kinds of use of geographic information in sufficient detail to permit the identification of costs and benefits attached to all or part of the decision-making process. However, information on costs and benefits at the level of detail required was not available in the case study. Therefore, attaching measures of costs and benefits to the petri net model was not performed, but was discussed and conceptualized in Chapter 5. By showing specifically how this detailed information may be used to represent costs and benefits, I have demonstrated that it is worthwhile for GIS installations to collect detailed performance data.

There are at least three uses of petri nets in determining the costs and benefits of geographic information use. The first involves the use of a petri net model to track the cumulative costs of a decision-making process. A second use can be found when a dollar benefit can be assigned to the end-product of the decision-making process. The petri net model can be used to proportionally allocate the benefits to both the geographic and non-geographic components throughout the process. The third use would be when a dollar value is established for an information product within the process (e.g., a map is sold). The petri net model could be used to verify that transaction value through the calculation of resource tokens to that point in the process.

The level of detail required in petri net representations is not known at present. For purposes of costs and benefit measurement, it may not be necessary to model the entire decision-making process at the level of detail used in the petri nets in this document. Sequences of steps that do not change the value of the resource measurement tokens could be selectively generalized. If, however, the model is to be used as a graphical representation of the process, then a common level of detail among all steps would be necessary.

It should be noted that two of the four tasks chosen for modeling were not represented in petri net form. Both the Old Growth Commission and the Fire History Map decisions were semi-structured decision-making tasks. Therefore, detailed documentation about each step in the process could not be collected. The Old Growth Commission process was not represented as a petri net because detailed documentation of the negotiations process did not exist. The decision to increase funding for fire prevention was not represented because documentation of the effects of the map information on legislative decisions was unavailable. The lack of representation is not a function of the chosen modeling technique, but rather, a reflection of the problems associated with studying semi-structured decision-making processes.

2. Outcomes of this Research

This research has provided the following:

- a literature review of methods for establishing the value of information;
- a literature review of modeling techniques;
- an introduction to petri nets as a technique to model the use of geographic information in decision making;
- an introduction of the concept of detailed modeling of decision making;
- an evaluation of modeling techniques and characteristics of complex decision-making systems;
- an example of using petri nets to model spatial decision making in Forestry;
- conversion rules between flow charts and petri net symbology;

- suggested modifications to petri nets to allow identification of costs and benefits.

3. The Next Steps in the Research

At least two activities are direct extensions of this research:

1. To test petri nets in a case study with complete data on costs and benefits;

2. Simulation of petri nets to check various properties of the decision-making processes.

The most direct extension to this research is to test the petri net in a real situation that provides the necessary data on costs and benefits. Once such detailed information is available, the resource measurement tokens can be operationalized and their use validated. This activity is limited at present by the lack of such detailed information. The information necessary to test the petri net model will need to be recorded over an extended period of time of decision making and will require time and effort on the part of the decision makers. However, this research has shown how this type of data could be used to determine costs and benefits of information use in decision making.

Another extension to this research involves the computerized simulation of a process through its petri net representation. The simulated net could then be analyzed in terms of reachability and liveness (Chapter 3). Once the costs and benefits are attached to the petri net model, the simulation of the process will calculate the values of these measurements. This extension to the research requires computer software to analyze the net. Such Software Is currently being developed as a cooperative effort between the National Center for Geographic Information and Analysis in Buffalo, New York and the Department of Geography at the University of Otago in New Zealand. The completion of this software will support continuing research in the application of petri net modeling to the evaluation of use of geographic information in decision-making processes.

Appendix A. Examination of Techniques for Modeling Process Behavior, Dickinson and Benwell, 1990, in draft form. Please do not cite or circulate.

Appendix B. Software Requirements for Petri Nets in the Behavioral Analysis of Spatial Information, Benwell and Dickinson, 1990, in draft form. Please do not cite or circulate.

Appendix C. Questions for Each Decision-Making Task
What is the name of the task?
What is the overall goal of the task?
What are the specific objectives?
Are these goals and objectives in written form?

What are the possible outcomes of the task?
What is the spatial extent of the task?
What is the time frame in which the decision must be made?

Are other persons involved in the task? (please list titles)
1.
2.
3.

How does the control of the decision making flow between the different persons? (try to draw a flow chart)

Please list the sub-tasks of the decision-making task and define the objective of each:
1.
2.
3.

Label the sub-tasks on the 'flow of decision making' diagram created above.

Are all sub-tasks performed each time: Yes No
If no, which ones are absolutely necessary?
If no, what decides if all sub-tasks are performed?

For each sub-task you perform...

Please list the steps performed (and define each):
1.
2.
3.

Which steps are performed within the GIS?

Which steps are performed outside the GIS?

Questions for each step...

Please list names of GIS product(s) used:
1.
2.
3.

List names of other geographic information products used:
1.
2.
3.

List other information products (non-geographic) used:
1.
2.
3.

For each GIS product used...

What is the required response time to receive the GIS product?
If the GIS product were not available...
how would the decision be made?
how would the decision be altered?
would the GIS product be created manually?
would some other product with similar information be used?

What are the steps involved in creating the GIS product?
(i.e., what functions, what data)

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