There Are Two Categories of PMS Analysis Methods: Reactive and Generative

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Two categories of pavement management system (PMS) analysis methods are proposed: reactive and generative. These terms are derived from two basic methods of thinking: event and systemic. Event thinking takes complex problems and breaks them down into a linear chain of events to make analysis more manageable. Event thinking focuses on detailed complexity and limits learning to event explanations. These characteristics are most useful for project analysis. Systemic thinking considers complex problems to have three levels of explanation: event (reactive), pattern of behavior (responsive), and systemic structure (generative). Systemic structure explanations are root cause explanations for the patterns of behavior observed. The reasons that root cause explanations are so important is that only they address patterns of behavior at a level at which behavior can be changed. These characteristics are most useful for network management. The standard structure for PMS conducts analysis as a linear chain of events whose products are not effective for managing large networks. The reason is that users cannot learn beyond the event explanation of their reactive analysis products. To be generative, PMS analysis methods must produce all three levels of explanations. This in turn makes it possible to manage networks by providing the information needed to control long-term funding levels and network condition, monitor the efficiency and effectiveness of proposed preservation programs and staff activities, and learn how economic efficiency can be improved by administrative and technical means.

This paper is based on management principles advocated by Senge in *The Fifth Discipline* (*1*). Senge, who is director of the Systems Thinking and Organizational Learning Program at MIT's Sloan School of Management, indicates that we are living in an increasingly complex world for which our formal education in linear thinking is no longer reliably effective. Complex systems, such as pavement management, require a shift from linear thinking toward systemic thinking. Linear thinking is most effective for solving problems that consist of detail complexity. But Senge indicates that there are two types of complexity: detailed and dynamic. In situations such as managing networks, for which cause and effect are subtle, effects over time are not obvious and the same action has different effects in the short and long runs, as in the case of using all short life treatments; here we have dynamic complexity. Conventional forecasting, planning, and analysis methods that are based on linear thinking are not equipped to deal with dynamic complexity. To deal effectively with dynamic complexity we must shift from linear to systemic thinking (*1*).

Network management is a complex issue that consists of the following levels of explanation: events (reactive), patterns of behavior (responsive), and systemic structure (generative). This paper proposes that the needs of network and strategic management systems are best served by analysis methods designed specifically for dynamic complexity, whereas project- and network-level analysis needs are best served by methods designed specifically for detail complexity. But the complex array of details that characterizes any management system distracts us from seeing patterns of behavior and the interrelationships among projects, preservation treatments, annual programs, networks, and trunkline systems. It appears, from proposed pavement management system (PMS) research needs, that it is necessary to devise increasingly complex solutions to increasingly complex management problems. The essence of systems thinking is seeing interrelationships rather than linear cause-effect chains—processes of change rather than snapshots (*1*). Systemic thinking methods simplify managing complex systems such as pavement networks, because they free us from detail complexity and help us see the deeper patterns behind the events and because they provide the ability to identify, understand, and control the vast array of interrelationships and patterns of change associated with pavement preservation.

This paper proposes that there are two categories of analysis methods for management systems—reactive and generative—and that AASHTO's PMS guidelines include only the reactive category needed for the detail complexity of project- and network-level analysis (*2*). It is also proposed that generative analysis methods are needed to provide pattern of behavior and root cause explanations needed for network and strategic management. The characteristics are described of generative analysis methods that differentiate them from the reactive methods that are in prevailing use. Network management primarily consists of dynamic complexity, and project and program development primarily consists of detail complexity. For this reason, two management systems are proposed, one for managing networks and one for managing programs. This necessitates linking the two systems with program development constraints.

DERIVATION OF TERMS

Event explanations are based on linear cause-effect thinking that focuses on breaking complex problems into smaller, easier-to-manage components that have less complex solutions (*1*). Senge refers to this process of thinking in terms of events as reactive. When reactive thinking is applied to developing analysis methods for management systems, the results are a series of component parts, the objective of each

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component being to reduce the number of variables with which the next analysis component must deal. An important characteristic of reactive thinking is the usual assumption that patterns of behavior are known. Event explanations are the most common in contemporary culture, and that is why reactive management prevails (*1*). For this reason, analysis methods that are reductive and based on event explanations are referred to as event or reactive analysis methods.

Pattern of behavior explanations focus on seeing longer-term trends and assessing their implications (*1*). They suggest how to respond to shifting trends over a longer term. Systemic structure or structural explanations focus on the underlying causes of patterns of behavior. The reason that structural explanations are so important is that only they address the underlying causes for patterns of behavior at a level at which behavior can be changed. Therefore, structural explanations are generative because only they enable us to create our own future. For this reason, analysis methods are referred to as generative when they deal with total systems, when they establish the patterns of behavior, and when they identify the underlying or root causes of patterns of behavior.

PAVEMENT MANAGEMENT VIA LEARNING OR NONLEARNING SYSTEMS

Learning systems provide all three levels of explanation (event, responsive, and generative), and nonlearning systems typically provide only event explanations. Therefore, management systems can be divided into learning and nonlearning systems, as illustrated in Figure 1. Learning systems consist of two separate systems. Policy makers and planners use the network management system to plan strategy, make policy, set the budget, monitor staff activities and programs, and control future network condition and funding requirements. Technical staffs use the program management system to select the combination of projects and treatments that meet program development constraints and maximize benefits at least program cost. The two systems are linked by program development constraints.

Nonlearning systems consist of network- and project-level analysis. Network-level analysis is used to determine network condition and the location of possible preservation projects. Project-level analysis is used to select the best treatment for each project. An optimization or ranking procedure is used to identify the best projects for the annual preservation program. This standard structure has no link between network and project levels that enables long-term control of network condition, budget requirements, and benefits. Furthermore, the operating characteristics of learning and nonlearning systems are totally different. For example, network management systems require detailed pavement condition data consisting of an inventory of each occurrence of distress by type, severity, and extent for 100 percent of the network. In contrast, network-level analysis needs only generalized pavement condition data based on a well-designed sampling plan.

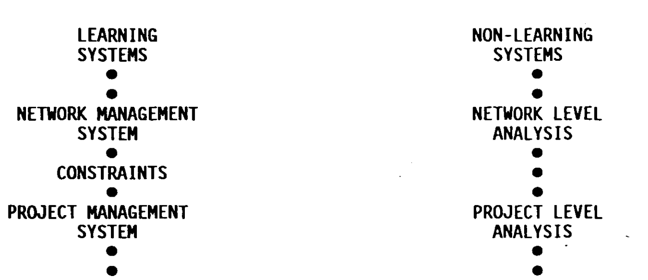

FIGURE 1 Two fundamental categories of PMS.

REACTIVE AND GENERATIVE ANALYSIS METHODS

Reactive analysis methods used for nonlearning PMSs include the following:

- Combined index for pavement condition
- Project life-cycle cost analysis
- Network-level analysis to identify maintenance, rehabilitation, and reconstruction (MR&R) projects
- Project-level analysis to identify best MR&R treatment projects
- Design service life estimates and pavement condition assessments based on different criteria
- Decision trees to select treatments
- Expert systems to select treatments
- Optimization to provide "the Optima program"
- Optimization based on selected projects and the best treatment for each project
- Requirement for an operational PMS staff
- Performance model for each pavement classification
- One level of optimization
- Duplication or replacement of pre-PMS program and project development process

The purpose of these methods is to formalize, essentially duplicate, and perhaps extend the pre-PMS project and program development process. When implemented, PMSs based on reactive analysis methods usually become an integral part of the project and program development process.

Generative analysis methods are listed in the following:

- Separate remaining service life indexes for roughness, rut depth, friction, and distress
- Detailed pavement condition data required for 100 percent of the network
- Network analysis based on project analysis of 100 percent of the network
- Network life-cycle cost analysis
- Network strategy analysis
- Automated project analysis
- Design service life estimates and pavement condition assessments based on same criteria
- Feedback process conducted by pavement research staff
- Network, MR&R program, and project performance based on
  - Percentage of length in acceptable condition
  - Remaining service life

- Three levels of optimization
  - –Network: maximize condition/cost
  - –R&R program: maximize benefits
  - –Project: minimize cost
- Performance model for each uniform section
- Not a duplication or replacement of the pre-PMS program and project development process

Their purpose is to establish the patterns of behavior observed for each network, to determine the underlying causes for these patterns, to control long-term (20 to 40 years) network performance and funding requirements, and to provide monitoring information. Their primary products are program development constraints that enable policy-level control of long-term network performance, funding level, economic efficiency, and monitoring capability. Any network preservation program that may be proposed by the technical staff must comply with the constraints set for that network. The quality of proposed programs is based on quantified measures of efficiency. The role for generative PMS analysis for network management systems is illustrated in Figure 2 and explained elsewhere (*3*).

IMPORTANCE OF SYSTEM CHARACTERISTICS

It should be important when developing a new PMS, or evaluating an existing one, to decide what characteristics the system should possess. The characteristics could then be used as constraints for selecting and developing the analysis methods.

Table 1 presents the characteristics that describe the products of generative and reactive analysis methods. If the first PMS development step were to select the reactive or generative product characteristics, more than likely the generative would always be selected. The point is that regardless of whether our thinking focuses on structural or event explanations, most of us prefer the product characteristics of generative analysis methods. However, when developing analysis methods, normal habits of linear event thinking prevail and the system ends up providing products like those on the right side of the table.

The following sections provide specific characteristics that differentiate reactive and generative analysis methods for pavement management.

Learning or Nonlearning Products

The use of reactive analysis methods explains only events such as network condition, project condition, and best project treatment. Learning is usually considered a research function, not a function of management systems. Reactive systems are usually designed to formalize the project and program development process. In this way they are parallel to and aide and improve the program and project development process. Reactive analysis includes various decision support methods such as decision trees and expert systems that are used to replace an individual's subjective opinion. However, according to diffusion of innovation concepts (*4*), reactive analysis methods should provide little relative advantage over pre-PMS program and project development methods.

Generative analysis for network management requires automated project analysis of all uniform performing sections within each network. This requires complete high-quality pavement condition, cost, and physical inventory data so that the automated project analysis products are accurate. Automated project analysis of the entire network for all feasible preservation treatments provides a huge pool of information from which application software systems are able to provide information needed to answer any conceivable question about network preservation. Automated project analysis provides what Senge refers to as leverage.

The term leverage means "seeing where actions and changes in structures can lead to significant, enduring improvements" (*1*). The objective of generative analysis is to provide the

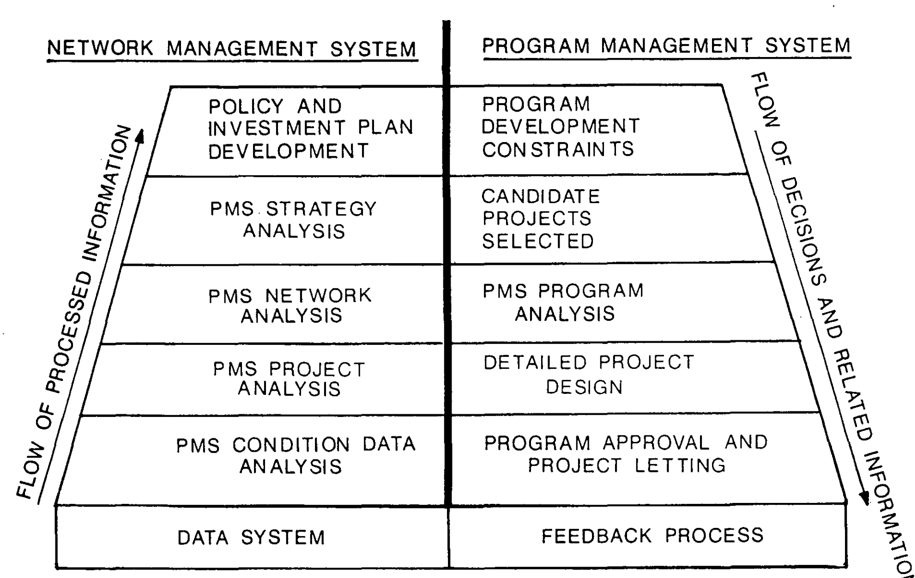

FIGURE 2 PMS structure for which decisions flow top down.

TABLE 1 Characteristics of Generative and Reactive PMS Analysis Methods and Their Products

Analysis Method	
Generative	Reactive
Learning	Nonlearning
Proactive	Reactive
Innovative	Noninnovative
State of the art	State of the practice
Generic	Agency-specific
Flexible	Inflexible
Simple	Complex
Decisions flow from top down	Decisions flow from bottom up
Cost-effective	Not cost-effective
Maximizes benefits	Does not maximize benefits
Truthful	Superficial

ability to see where high leverage changes are possible. For example, network (or program) life-cycle cost analysis (*5*) and strategy analysis (*6,7*) provide the information needed to see how improvements in long-term network condition can be accomplished with no increase in funding. This ability to learn from the system is illustrated elsewhere (Novak et al., unpublished data, 1993).

Generative analysis products are used by upper managers to learn what pavement preservation funding level would be required to meet long-term network condition objectives at the lowest network life-cycle cost. All three levels of explanation are needed for such a learning process. Examples of each level are as follows:

1. Event explanations include network condition and the lane-mile cost of available projects of a given cost-effective range.
2. Pattern of behavior explanations include network remaining service life and the long-term network condition resulting from a given network strategy (a network strategy is the lane-mile length and the average design service life of the annual program).
3. Underlying or root cause explanations include lane miles of pavement designed to be moved from each lower to each higher remaining service life category and the primary cause of network deterioration.

The information from generative analysis can be used with other information to arrive at informed decisions that enable accomplishments such as controlling and creating future network condition and funding streams, improving economic efficiency, reducing administrative overhead cost, determining the research projects that would most improve economic efficiency and program benefits, and analyzing the cost-effectiveness of staff activities such as pavement research and cost estimation.

Generative analysis methods are used by technical staffs to learn, via the feedback process, how to improve the accuracy of estimates such as project cost, benefits, and design and remaining service life. Feedback is a data processing activity that provides processed information that technical staffs need to improve economic efficiency. For example, research can use the primary cause of network deterioration as its primary research effort. If research is successful, it should lengthen network remaining life, improve network condition, and increase funding efficiency. The cost-effectiveness of the research staff is a function of the cost of research and the dollar value of the improved economic efficiency that it has produced.

Network management based on generative analysis provides relative advantage over the pre-PMS project and program development process. Advantages include a simplified and accelerated learning process, better communications between technical and manager staffs, the direct use of technology to attenuate the effects of inadequate revenues, and funding efficiency that is controlled by administrative users and improved by technical users.

Proactive or Reactive Products

Proactive refers to the ability to provide upper managers with the information needed to create the desired future network condition, associated funding streams, and investment benefits. Proactive, as used in this paper, does not refer to the aggressiveness with which agency problems (both internal and external) are attended to. To be proactive, a PMS must provide for decisions to be based on all feasible alternatives and to flow from the top down, for monitoring capability to ensure that constraints are followed, and for feedback to compare actual with estimated results. Generative analysis for network management provides the ability to control future network condition and funding streams rather than react to them. This gives managers (users) a relative advantage over pre-PMS methods since the long-term outcome of any feasible alternative funding or preservation scheme can be readily displayed by means such as simple bar charts and a network analysis chart (*8,9*). The technical staff also gains relative advantage in that the management system becomes a means by which to learn, to communicate with upper managers, and to use technology directly to improve economic and benefit efficiencies.

Generative analysis methods provide managers, designers, materials engineers, cost estimators, and research personnel with processed information and data that indicate what must be done to improve economic efficiencies, benefits, and effectiveness of available funds. The products of linear event analysis methods create a climate of compliance for which individuals pursue narrow goals. Generative analysis methods enable individuals to see beyond their self-interest and to have new energy and commitment to organizational learning and improvement.

Measurement of Economic Efficiency

Generative analysis methods are capable of measuring economic efficiency. Efficiency measures provide relative advantage over pre-PMS methods because managers are given the means to learn how to maximize network condition and the benefits derived from available funds. For example, few managers realize how nonuniform pavement performance is and how much this effects economic efficiency. Efficiency measures enable their users to comply with the economic efficiency objective of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA).

Efficiency measures also furnish monitoring capability and supply the reasons that proposed programs are not as efficient and effective as desired. The value that users derive from generative analysis methods can be measured in terms of the improvement in funding efficiency that takes place over time. Reactive analysis methods cannot provide this capability. The reality of reactive analysis methods is that they do the best they can with the data available; however, it is not known just how good that is.

Innovative or Noninnovative Products

Innovative refers to the ability of generative analysis methods to accommodate and facilitate creativity and innovation in the development and improvement of analysis methods and in the use of its products to develop alternative funding schemes. Noninnovative refers to products of reactive analysis methods that generally parallel the agency's pre-PMS methods. No new information, no new products, and no new means to use the analysis products to develop more creative and innovative preservation programs or funding schemes are offered. Nor do reactive methods give technical staffs the means to be more creative or innovative. The ability of generative analysis methods to enable all staff levels to be more creative and innovative gives them a relative advantage over current practice and reactive analysis methods.

Users of network management products are upper managers and planners, whereas appropriate technical staffs have responsibility for the quality and completeness of the data and analysis methods used and their products (*3*). For network management based on generative analysis methods, the three key variables are cost, design and remaining service life, and lane-mile length. These variables have equal meaning and importance to technical, planning, manager, and policy staffs; hence, communication among these staffs is simplified and improved. Even the influence of a material property as obscure as effective porosity can be traced to funding efficiency. Likewise, managers can trace less-than-desirable funding efficiency down to underlying causes such as bases that are subject to seasonal softening and their corresponding effective porosity.

To try out reportedly creative and innovative ideas should not be confused with actually being creative and innovative. Reactive analysis methods can accommodate working with and incorporating materials, methods, and ideas reported to be creative or innovative. However, reactive analysis products are not intended to foster creativity or innovation. Users of reactive analysis methods must therefore either comply or not comply with their analysis products. And since reactive analysis methods generally formalize and centralize the program and project development process, Kalia indicates that this generally inhibits innovation (*10*).

State-of-the-Art or State-of-the-Practice Technology

State-of-the-art technology refers to an analysis method's ability to use technology to improve economic efficiency. Reactive analysis many employ high-technology analysis methods such as linear programming to find optimal combinations of projects for the annual program. However, the use of high-tech methods does not necessarily result in good products or the efficient use of available funds. Generative analysis methods are designed so that the technical staffs can at any time improve the accuracy and reliability of the analysis methods. To do this, an agency's pre-PMS era pavement research, pavement design, cost estimating, and materials staffs must, in the post-PMS era, have full-time responsibility for the PMS feedback process (*3*). Research efforts can then be directed at problems that would make greatest improvements in economic efficiency and program benefits. Furthermore, unless automated project cost and design life estimates are reliable and accurate, it would not be possible to use generative analysis methods. Therefore, cost estimators and pavement designers must track the accuracy of cost and design life estimates and take corrective action as needed.

The exclusive use of reactive analysis methods stagnates the agency with state-of-the-practice technology and the associated inability to actually use technology to improve economic efficiency. This has created a problem that is pointed out by Hudson and Haas (*11*). Their concern is that "pavement management implementation experience suggests that many of the same problems found in PMS in the 1970s still exist in the 1990s." This reflects the nonlearning nature of PMSs that are now in use and that are based on reactive analysis methods.

Generic or Agency-Specific Analysis Methods

Network management based on generative analysis methods requires the following variables: lane-mile cost, design and remaining service life, and lane-mile length. It is not directly involved in the selection of treatments, projects, and programs. For these reasons, generative analysis methods are not agency-specific but generic, and they deal only with the objective aspects of network management. Generative PMS analysis methods are explained by Kuo et al. (*6*), and their generic nature is demonstrated by Novak et al. (unpublished data, 1993;*12*). To be generic, the analysis method must consist of only application software. A customized utility software system is needed to adapt application software products to each agency.

Generative analysis products for network management are used primarily by upper managers to develop preservation program constraints and to review the economic efficiency of proposed programs. This use ensures compatibility with the agency's existing operating procedures and organization and avoids problems with detail complexity that is associated with decisions about which treatments and projects to select, political and demographic considerations, and factors related to priorities and ranking methods that cannot be quantified.

Flexible or Inflexible Analysis Methods

Network management based on generative analysis methods is flexible since upper managers are totally unrestricted by it. The analysis products simply provide the outcome of any alternative funding or network preservation scheme. For example, what estimated reduction in administrative overhead cost should occur as a result of increasing the average remaining life of a network by 2 years? Or, what would be the best possible network condition that could be maintained with a given funding stream? Flexibility is also enhanced because decisions flow from the top down, as shown in Figure 2. Reactive analysis tends to be inflexible because alternatives are narrowed down until there are few left. Generative analysis allows projects and treatments to be selected in any way the agency chooses. The quality of proposed programs is measured in terms of their economic efficiency and the quantified benefits they provide.

Generative analysis methods are flexible because during the preprogram development process, managers can inquire into any proposed funding or preservation scheme and evaluate its pluses and minuses. Once the program constraints that provide the desired long-term network condition and funding stream are identified, the technical staffs are free to assemble alternative programs in any way they think is most appropriate. This in turn provides competitive opportunities. Upper managers have efficiency measures to determine the quality of proposed programs and to evaluate the cost-effectiveness of their staff. For example, a district whose preservation program's funding efficiency is 40 percent would require in-depth review if the efficiency of another district's program was 60 percent.

Simple or Complex Analysis Methods

Network management based on generative analysis methods provide simplicity not possible with reactive analysis methods. Much of the effort that goes into reactive methods deals with reducing the number of variables that must be considered in the next analysis step, in managing large volumes of data that are used for reference purposes and establishing performance curves, and in overcoming problems caused by not having complete, high-quality data for network and project analysis. Generative analysis requires more and higher-quality data on pavement condition, unit cost, and physical inventory than are used for reactive analysis. These data requirements are necessary to automating project analysis and getting accurate products. But this simplifies everything else. The many computations needed for generative analysis can be made in seconds, thanks to the brute-force capability of modern computers. And the problem of storing huge quantities of data products is avoided by converting the data to various matrices that are used for strategy analysis (*6*).

Generative analysis methods simply forecast the outcome of any given decision. Agencies can then use the system to track real outcome with that forecasted by the analysis method. This form of trialability (*4,10*) enables users to continue with current operational procedure while gaining experience and an understanding of its products and forecasting capability. New operational procedures can be phased in as a result of the learning process afforded by the trialability of generative analysis methods.

Generative analysis methods require the use of remaining service life (*13*) because it is a pattern of behavior of projects, programs, networks, and total systems and it must be controlled. The use of remaining service life provides simplicity because it has a linear relationship with time, because it provides a measure of the network's condition (percentage of network in poor condition is the same as the percentage of network with zero remaining service life), and because it simplifies relating the impact of alternative treatments, projects, and programs on the long-term condition and funding needs of the network. Network or program life-cycle cost analysis (*5*) is less complex than project life-cycle cost analysis and provides the following advantages:

- Managers have greater flexibility when establishing budgets and network condition objectives,
- It demonstrates how preservation programs can be made more economically efficient, and
- It provides the ability to measure funding efficiency and benefits of alternative preservation strategies and programs.

Network strategy analysis (*6,7,11*) provides a simple means to evaluate the network patterns of behavior resulting from any feasible alternative network strategy or funding scheme over a 40-year (or more) analysis period.

Top-Down or Bottom-Up Flow of Decisions

The generative analysis methods used for network management are indicated on the left side of Figure 2, and the agency-specific program management system is on the right side. The left side activities are automated, administrators and planners are its users, and program development constraints are its products. Constraints are program cost, design service life, lane-mile length, and benefit priorities. The right-side activities are conducted in conformance with program constraints using any methods that the agency desires. The quality of proposed programs is measured in terms of their efficiency and the benefits that they provide. This is a top-down program development process that is explained in more detail elsewhere (*3*).

Current thinking is that policy-level activities can be based on low-quality, incomplete pavement information with an increasing need for quality and completeness at the project and then research levels. The advantage of incomplete information of low quality is the freedom to do as consensus agrees is best with little fear of accountability. If revenues fall short of needs, this same incomplete, low-quality data can be used to justify proposals to increase revenues without fear that outside review could successfully challenge them. It is not that state highway agencies (SHAs) will try to raise revenues without justification. Instead, it is far more difficult to make more efficient and effective use of available funds than it is to secure needed revenue increases based on current state-of-the-practice methods and consensus. And nonlearning organizations are compelled to seek easy solutions to difficult problems.

Whereas most upper managers would probably prefer a top-down flow of decisions, such a flow brings with it accountability, greater responsibility, and the need for more technical and management skills. Reactive systems are, after all, designed to continually narrow down the alternatives. Managers generally do not realize how much this reductive process diminishes their decision-making prerogatives.

For example, in Michigan the director needed to establish the funding level for pavement preservation. Subordinates provided the following three alternatives: a budget level that (a) provided good system condition but required serious underfunding in other categories, (b) allowed adequate funding of the other categories but would cause the system to deteriorate to unacceptable levels, or (c) provided acceptable system condition and was affordable. Which funding level would you select, and who really made the decisions?

Good or Poor Cost-Effectiveness

Generative analysis enable users to determine the cost-effectiveness of the PMS and its various support activities. The automated project analysis method generates the huge pool of data previously described. This data source provides the total possible benefits and associated costs available within the system. It is similar to determining the total energy available in a unit of gasoline and using that as a basis for determining the efficiency of alternative engine designs. Many practical constraints prevent us from doing that which is theoretically possible. In addition, the ratio of that which is theoretically possible to that which is proposed to be done is a measure of efficiency. If, through the use of generative analysis methods, it is found that efficiency can be improved, the amount of improvement can be converted to the dollar value derived. Hence, the value or cost-effectiveness of generative analysis is easy to determine.

This is not so for reactive analysis methods. Likewise, the dollar value of improvements developed by research, design, cost estimating, materials, and so on can be calculated on the basis of the effect they have on funding efficiency. For example, if research enables funding efficiency to be improved by 1 percent, the value of that research is equivalent to 1 percent of the cost of the annual preservation program. This same idea applies to the other activities involved in the feedback process. The generative PMS also gives policy makers the reasons that proposed programs are not 100 percent efficient. The dollar value of a generative management system is measured in terms of the improvement in funding efficiency that it provides. Management systems based on reactive analysis provide little opportunity to quantify their dollar value or their return on the agency's investment in its development and operation.

Does or Does Not Maximize Benefits

The network management system's automated project analysis computes the benefits derived from all feasible treatments for all uniform sections that make up the network. For the program management system shown on the right side of Figure 2, a PMS program analysis software system is provided to enable the engineering staff to assemble and rank combinations of projects and treatments that best maximize benefits. To do this, users list enough projects for three or more annual preservation programs, and the software system assembles alternative programs that meet program development constraints and maximize benefits and then places them in rank order. This procedure is presented in the AASHTO guidelines (*2*) and is explained in detail in a paper now in preparation for the Third International Conference on Pavement Management. The abilities to maximize benefits, control long-term network condition and funding requirements, and learn how to further improve program benefits are not possible with reactive methods.

Reactive methods convert benefits to dollar value and discount them to their net present value. This is an inflexible approach since managers cannot emphasize different benefits in line with current social, economic, and political needs. As a result, management prerogatives are diminished since the benefits provided by selected programs are limited to that which the preselected candidate projects and treatments will provide. Furthermore, nothing will be learned of the relationship between the benefits provided by alternative programs and those that are technically possible.

Truthful or Superficial Products

It is important that management systems not deceive their users. The questions for which honest answers are needed address what is really going on out there and what will really happen if this or that alternative is chosen. Senge indicates that a commitment to the truth does not mean seeking the truth, the absolute final word, or ultimate cause. Instead, it means a relentless willingness to root out the ways in which we limit or deceive ourselves from seeing what is, and to continually challenge our theories of why things are the way they are. In this respect, generative analysis methods provide observability (*4,10*)—that is, the effects a given long-term funding stream and network strategy have on network condition can be observed each year and evaluated for accuracy, reliability, and the like. In this way, the reliability and accuracy of past decisions can be monitored and used to improve the current decision-making process.

Reactive analysis methods provide superficial products that are considered safe and acceptable: the projects, treatments, condition, and programs. The joy of reactive systems is that decisions can be made on the basis of data so general that outside sources cannot use the data later to question the wisdom of agency policies and objectives. The nature of management systems based on reactive analysis is in complete contrast to the accountability possible with learning systems and their generative analysis methods. Generative analysis methods cannot be developed and operated on superficial definitions and generalized data. Few agencies may wish to have the results of their decisions publicly scrutinized, which may eventually happen with the use of generative analysis methods. So what incentives are there to change the way we think about complex pavement management issues in order to make better use of federal funds?

SUMMARY

Based on learning organization principles presented by Senge (*1*), SHAs have one of two alternatives: to continue using the standard structure for PMS and reactive analysis methods, or to include generative analysis methods for network and strategic management purposes and reactive analysis for project- and network-level analysis needs. The second alternative requires two management systems—a network management system (for policy makers) and a program management system (for technical staffs)—and a link between the two systems referred to as program development constraints (see Figure 2). Reactive analysis methods are intended for analytical problems that involve detail complexity—that is, problems that can be solved by breaking them down into a linear chain of events and then solving each event independent of the other. However, this paper points out that when network management is conducted in this way, learning cannot go beyond event explanations. Policy makers are then left with no means to control future network condition and budgets; hence, their only choice is to react to the event explanations of the PMS analysis methods. This is the reason for referring to analysis methods that provide only event explanations as reactive.

Networks are systems that have dynamic complexity. For networks, the long-term cause-and-effect relationship between their performance and annual preservation programs are subtle, and because the same action can have different results in the short and long runs, there is dynamic complexity. Systemic thinking is that for network management, it is necessary for the analysis method to provide pattern of behavior and systemic structure (root cause), as well as event explanations. Pattern of behavior explanations focus on seeing longer-term trends and assessing their implications. Network remaining service life distribution is a pattern of behavior required for network management. It must be established on the basis of complete, accurate, and reliable pavement condition data. Systemic structure (root cause) explanations are the least common in pavement analysis and the most powerful. They focus on identifying the causes of the observed patterns of behavior. The reason root cause explanations are so important is that only they address the underlying causes of patterns of behavior at a level that behavior can be changed. When PMS analysis methods provide all three levels of explanation, policy makers then have the information needed to control their future in terms of network performance, budget requirement, and benefits.

The Michigan Department of Transportation's PMS is a network management system that is based on the generative analysis methods described in this paper. The system has been approved by FHWA and has been recognized to be ideally suited to the strategic planning process required by the ISTEA legislation. Because of the monitoring capability of network management systems, it is not necessary to have a program management system. An agency's current project and program development system could continue to be used in conjunction with the network management system.

CONCLUSIONS

1. Project and network level analysis are complex problems consisting primarily of detail complexity for which reactive analysis methods and their event explanations are well suited.
2. Network and strategic management are complex issues consisting primarily of dynamic complexity for which analysis methods must provide event, pattern of behavior, and root cause explanations.
3. The standard structure for PMSs described in the AASHTO's guidelines offer direction for developing analysis methods that deal with the detail complexity of managing projects and networks; however, they provide little guidance for developing analysis methods that deal with the dynamic complexity of network and strategic management systems.
4. It should be necessary for SHAs to use generative analysis methods, a network management system, and program development constraints, if policy makers are to control future network condition and funding requirements, improve the economic efficiency of available funds, and monitor the efficiency and effectiveness of their PMSs and the subordinate staffs involved in project and program development.
5. Generative analysis methods require complete, accurate, and reliable data on pavement condition, physical inventory, unit cost, and pavement design.

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