A Researcher Looks at Maintenance Management—In a "Systems" Context

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There are as many definitions of "systems analysis or approach" used today as there are people who use the term. I have my own which stems from my engineering background. Systems analysis, in a simple discription, is an attempt to optimize or improve the system under consideration. It is generally approached through the following steps:

1. Definition of the system under study, including objectives.
2. Identification of the system components, the structure.
3. Definition of the relationships and interactions between the system components.
4. Definition of the problems or conflicts in system component interactions and relationships.
5. Application of technology to the problems or conflicts encountered. It is in this step that the use of operations research, including mathematical models using exact or approximate causal relationships, is brought into action. Through a series of iterations an attempt is made to optimize the variables involved, and come up with at least one best solution, or several best solutions.
6. After the alternatives or best solutions are developed, it is necessary to test these solutions, including the use of judgment in some instances where factual data are lacking. This testing effort also has the side-effect of generating specific knowledge about research or problem solving techniques that are needed for a more complete solution to the problem.
7. Armed with factually developed data, temporized by good judgment where necessary, the decision-makers are then in a position to make a rational choice using the best solution to optimizing or improving the system under consideration.

Systems analysis is not a panacea for all management aches and pains, but it is a rational approach to some of the current problems in optimizing maintenance management. Most civil engineers of my generation were unknowingly introduced to the systems approach by our old friend, Hardy Cross.

If we are to use the "systems" approach to improve highway maintenance management, we must first define the system under study.

RELATIONSHIP OF MAINTENANCE TO THE "HIGHWAY SYSTEM"

Through a system of mandated or dedicated taxes to support highways there has been a tendency to set highway systems apart from the remainder of public environment. Those who live in major central cities, or in states where urban needs are the greatest, are seeing the results of this approach expressed by opposition to plans for highways and the mandating of tax revenues. It is becoming apparent that if we are to "optimize" our urban environment, there is going to be increasing pressure to look at the urban area as a "system" in itself. To tackle the urban area as one system is complex, so we would start to decompose the system. One might depict the urban environment as consisting of some major subsystems as shown in Figure 1.

Within each of these subsystems there are many sub-subsystems; for example, in the public works area, we might define the need for shelter for human activities, transportation of all kinds, natural resources, and, becoming more important, the waste system. As shown in Figure 2 each of these subsystems has forces of optimization which are in conflict in many instances. When we consider that the optimization of one

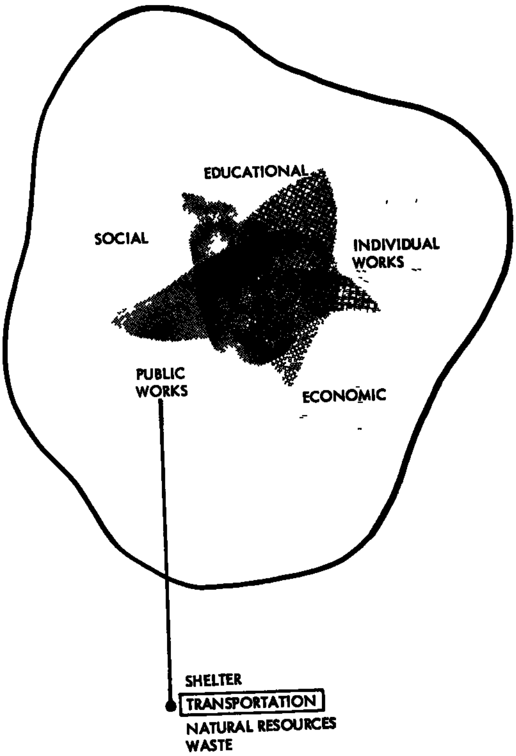

Figure 1. The urban system and its major subsystem areas.

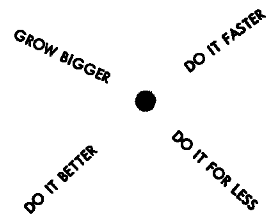

Figure 2. Forces of optimization in conflict with urban areas and systems.

system may detract from or compete with the optimization of another system, the number of solutions to any urban problem approaches infinity. Recognizing the difficulty in trying to approach any sort of valid rationalization across the whole spec trum of the urban environment, we are forced to seek suboptimization. Frankly, we do not have enough knowledge or factual data to do any more than seek suboptimization, and rely on social pressures, political judgments, and, hopefully, common sense to bridge the gap between the major competing urban systems.

Fortunately for highway maintenance people, we are not faced with the problem of th magnitude faced in the whole urban system. The problem in highway maintenance management is a bounded system. Although there are many intangibles involved, we can describe fairly accurately our maintenance world because it is represented by the physical existence of real property—roads, bridges, traffic signals and signs, drainage structures, and buffer land. Each of us could make some fairly valid judgments on the adequacy of maintenance for a particular small segment of a road by observation. Getting this same kind of judgment expressed for a whole state road system complicates the problem significantly. If we were satisfied with our highway maintenance systems, we would not have this workshop. If we are to compete successfully for resources in a changing urban environment, we must have a system that not only makes sense to us, but also carries our message up the line to others, in a way that relates to the whole of our urban environment. I will try to indicate some approaches that I think would help us in improving maintenance management.

All of us are familiar with the life cycle of real property. Figure 3 identifies the major events in the life cycle that have an impact on highway system management. Be fore maintenance personnel are given the responsibility for the road system, many decisions have been made over which they have no control. Most of these events are controlled by engineers, and, therefore, the opportunity to use the same language in communications exists. Although we can describe the event relationships over the lif cycle of the highway system, that does not per se solve the communications problem. Because you must maintain what the designers and constructors build, a good system must provide for feedback. In summary then, we can define the highway system, iden

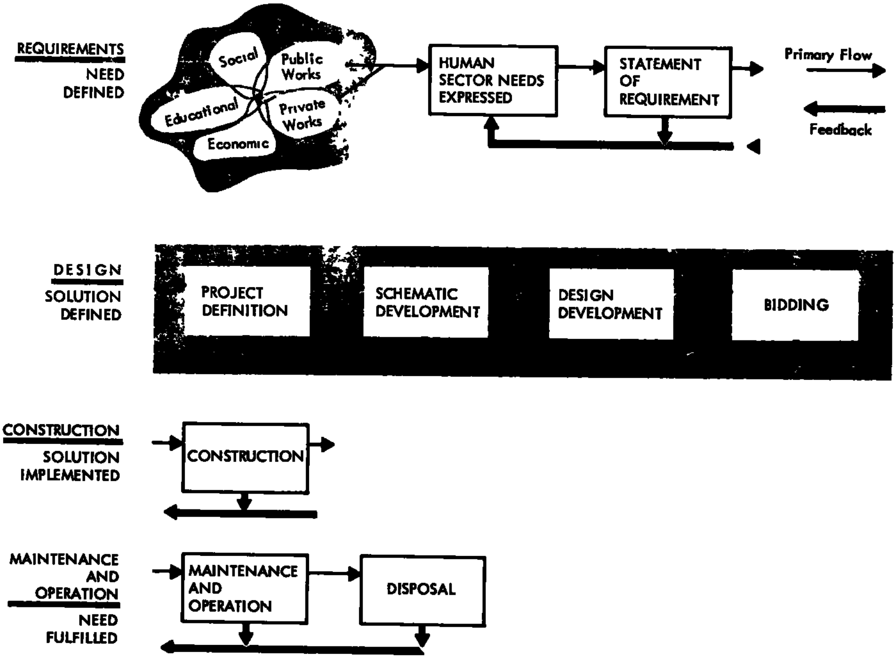

Figure 3. Major process events in the life cycle of real property.

tify its life cycle, and the major events in the life cycle where decisions and management action are possible. We can make a fairly substantial case that it is to a great degree a closed system, once human needs requirements are determined. In short, from a systems approach the highway maintenance management program can be readily rationalized. The next question we might ask ourselves is whether maintenance management is a classic management problem? Can we find mathematical models developed for other management problems that will work?

MAINTENANCE—"CLASSIC" MANAGEMENT PROBLEM?

The functions of management as outlined by authoritative writers are described in different words, but three main word descriptors appear to dominate the literature. These are plan, execute, and appraise. Under planning, we set objectives, organize the effort, and assign responsibility. In execution, we carry out the plan exercising good judgment. Appraisal provides us with the necessary feedback to monitor performance and to provide the basis for replanning. Each of these elements of management is part of every viable maintenance program.

From a modeling standpoint, maintenance could be related to a modified inventory problem. We have an inventory of roads which must be maintained. The roads might be considered to have a "shelf life." Periodically they must be renewed to original or serviceable condition, with the objective of maintaining the inventory in usable condition. If we could predict shelf life expectancy, and the repairs required at the end of the shelf life period, we should be able to establish an effective management model for highway maintenance. Similarly we could consider highway maintenance as a dynamic equipment problem because of its wear characteristics from traffic. Workable mathematical models exist for management decision-making aids in both these cited cases. Both of these models, however, require the ability to determine a failure condition. To make the model work we must be able to describe failure.

It would appear that our first problem in trying to model maintenance management for highways is that we are faced with two contributors to failure, natural deterioration from the elements (akin to the inventory problem), and wear from traffic (akin to the dynamic equipment problem). The problem is made a little tougher in that we must also state what constitutes failure. As we all recognize, a rather bad road from a riding

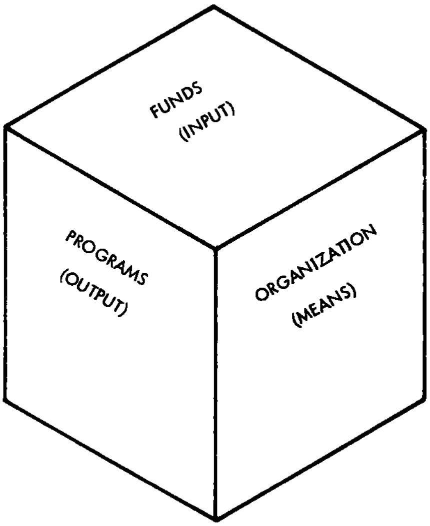

Figure 4. Typical management information matrix for decisions and planning.

standpoint is still usable. Therefore, a clear definition of failure is hard to produce.

Maintenance management on the other hand is a classic problem from the functions of management standpoint—plan, execute, and appraise. To my knowledge no one has developed a mathematical model for highway maintenance using the existing management models that have been developed. So our problem appears to be classic in the functional sense, but atypical in the modeling sense. This by no means indicates that we cannot do a good job of maintenance management, but only that we have to tackle it in another fashion, at least for the time being.

The approach which has been used successfully in maintenance management relies on structuring a management information system to provide historical data as an aid to management decision-making. Figure 4 is a typical management information matrix for structured decisions and planning. Starting with the output of the system, generally stated in programs, the means or organization for accomplishment is

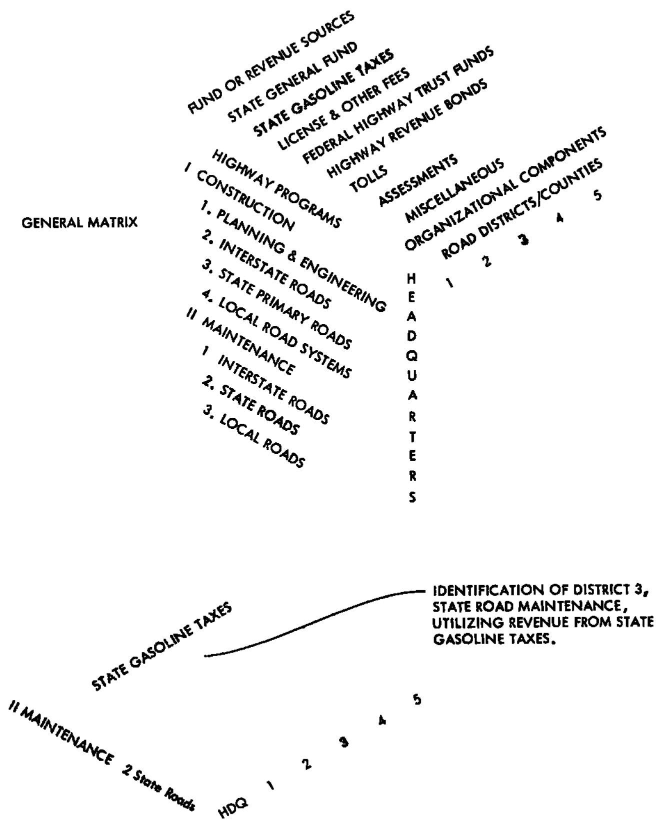

Figure 5. A potential budget framework for a state highway department.

developed, and the input or dollars to support the means determined. In the days before state and interstate roads, one source of funds, one organizational element, and one class of roads described the problem fairly adequately. To be able to approach the same information base today, the amount of information required is compounded significantly as indicated in Figure 5 for a potential state highway budget framework. Prior to the development of electronic data processors such an information system would have been impossible to maintain, much less use for management needs. While the problem is still formidable, the solution is feasible. Until we are able to develop a valid highway maintenance model the use of a historical-based cost and budgeting system appears to offer the best potential for management of the maintenance function at the state level. The development of the budget on a program or output basis, while subject to some assumptions, provides management with a rationalized base for decision-making in the resource allocation process. If we built the best mathematical model possible, the objection would still come up from the field, "But my district is different." With the recognition that we can use a workable budget and information system, for management and information exchange between state and district or county level, there must also be a functional management system in operation.

THE MAINTENANCE MANAGEMENT CYCLE

Because of our inability to predict specific maintenance jobs reliably, the best maintenance management systems are based on inspection generated work identification. Although the program budget and management system should provide overall guidelines for the amount and type of work to be performed, it is still necessary for a trained man to eyeball the road for specific deficiencies. With the deficiencies uncovered, the inspection generated word is planned and estimated for the working supervisor. It is the supervisor's role to manage the men and equipment to accomplish the work outlined. The feedback of costs and accomplishments versus plan provides management with the status of work in hand. This planned approach to maintenance has been widely adopted, and has resulted in reducing the cost and improving the quality of maintenance. Figure 6 shows the typical organizational makeup (administration,

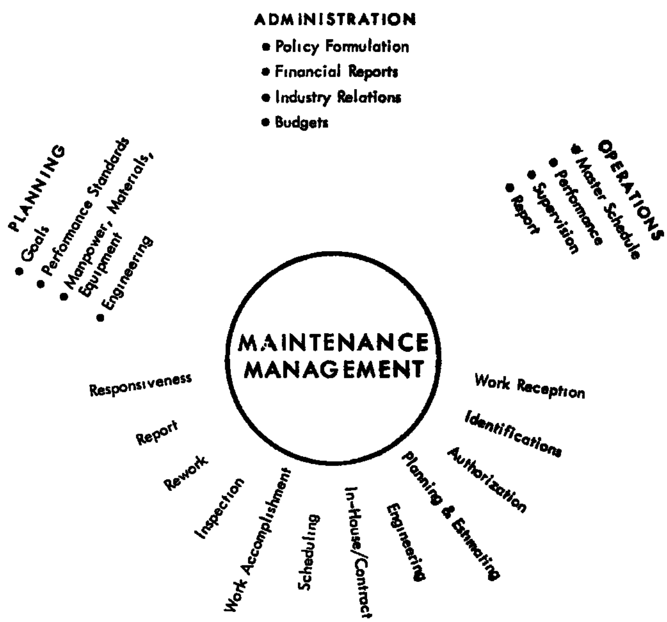

Figure 6. Maintenance management cycle.

FUNCTIONS	LEVELS OF SOPHISTICATION		
POLICY	**VERBAL**: none expressed; custom and usage; verbal to key people; brief top level instructions	**WRITTEN — INCIDENT GENERATED**: written general guidance; written specific guidance; plus contingent guidance	**FORMAL STATEMENTS AND DETAILED PROCEDURES**: printed and published; plus updating; plus contingent guidance
ORGANIZATION	**UNSTRUCTURED BASED ON INDIVIDUAL ASSIGNMENT**: craft; shop; function (e g housing utilities etc)	**STRUCTURED**: area (geographic); craft or shop; function	**STRUCTURED AND CONTROLLED**: plus maint control staff; plus financial management and cost control staff; plus self contained support (supply procurement & transport)
LEVEL OF MAINTENANCE	**UNPLANNED**: user (do it yourself); breakdown (at time of occurrence); haphazard or random	**PLANNED**: scheduled; plus back log control; partial preventive maintenance; comprehensive preventive maintenance	**PLANNED AND CONTROLLED**: plus feedback; plus maintenance engineering
WORK IDENTIFICATION	**UNPLANNED**: complaints; emergency service calls; routine service calls; operator inspections; supervisor inspections	**SIMPLE STDS**: mfr health, safety stds; scheduled inspections	**PLANNED**: planning and estimating; plus preliminary engineering
WORK RECEPTION	**REACTION RESPONSE**: individual workers; supervisors; dep t staff	**FORMAL WORK RECEPTION AND CONTROL**: dayshift receptionist; screening plus additional clarification and feedback; 3 shift receptionist; screening plus additional clarification and feedback	
PLANNING & ESTIMATING	**WITHOUT STANDARDS**: none; rough by journeymen; rough by supervisors	**EXPERIENCE STANDARDS**: rule of thumb at any level; published standards by others; P & E group in shops; P & E group at staff level	**FORMALLY DEVELOPED STANDARDS**: plus engineered performance standards; plus consulting firms; plus maintenance engineering
WORK AUTHORIZATION	**VERBAL**: customer; shop; staff	**LIMITED FORMAL**: policy instructions; system standing job order; supervisor approval specific j o	**FORMAL SYSTEM WITH DEFINED AUTHORITY**: specific j o approval staff; specific j o approval senior staff; specific j o approval PW director
SCHEDULING	**INFORMAL**: none; first in first out; fixed priority by work classif	**PARTIAL FORMAL**: major jobs scheduled; scheduled preventive maintenance	**TOTAL SCHEDULED AND FORMAL**: all in house work and contract work; by scheduling engineers
WORK PERFORMANCE	**INFORMAL**: visual; watch standing; routine patrol and inspection	**PARTIAL CONTROL**: service work controlled; major work orders controlled	**TOTAL CONTROL**: all work controlled
MAINTENANCE CONTRACTS	**UNSCHEDULED**: none; peak work load	**SCHEDULED**: periodic	**PLANNED AND BUDGETED**: complexity or limited dollars; planned annual
EVALUATION & ANALYSIS	**INFORMAL**: none; customer complaints; breakdowns and emergencies; verbal inspection reports	**SIMPLE CONTROLS**: written inspection evaluations; rework effort; work sampling	**DETAILED EVALUATION**: detailed comprehensive cost effectiveness analysis
BUDGETING	**INFORMAL**: level budgets; current payroll plus estimate of materials and services	**FLEXIBLE AND INFORMAL**: fixed percent of plant investment; adjusted per cent of plant investment; adjusted historical cost basis	**DETAILED FORMAL AND FLEXIBLE**: based on maintenance control forecast for level of facility maintenance; planning programming and budgeting systems

Figure 7. Maintenance management profile.

planning, and operations) that has been adopted by most alert maintenance management organizations. The functions of each of the organizational elements are indicated. The elements of the maintenance management cycle are also shown. The management functions of planning, execution, and appraisal are adequately covered with a system of checks and balances developed by the cycle and the assignment of functional responsibilities.

ORGANIZING FOR MAINTENANCE MANAGEMENT

There are few occasions where one has to start from scratch in organizing for maintenance today. In our work with clients who are trying to improve their maintenance management programs, we developed a maintenance management profile (Fig. 7). In looking at the adequacy of our client's maintenance management programs we felt the need for a simple working tool that would help us identify potential sources of problems, and which would provide a profile of levels of sophistication in management. Our observation is that many systems for the management of maintenance get out of balance. The simplest analogy that I can make is perhaps to use my Volkswagen as an example. I could install a hopped up motor and get the necessary power to use it for road racing. But unless I beefed up the clutch and the suspension gear, it would be a rather dangerous machine. In short, by not balancing the capabilities of the "Bug" I have destroyed the overall system design.

On the left-hand side of the profile (Fig. 7), we have identified the major functions required in a maintenance program. In the columns to the right we have identified the levels of sophistication of the various management functions. In general, we start on the left with an unplanned, loosely structured approach with few controls, and because of the lack of planning, no formal feedback mechanism. As we progress toward the right the management devices that we introduce become increasingly sophisticated. On the far right the most sophisticated devices for management are being utilized. By checking off the appropriate level of sophistication for each of the functions, and then connecting the checks with a line, we develop a vertical profile which provides us with a good overview of the management system balance. From this point we are then able to determine the best way to get balance in the maintenance system, and to suggest the appropriate devices or techniques which should be incorporated. Most highway systems are large enough that they require and can economically support a fairly sophisticated maintenance management system. Each of you might like to evaluate your own management profile to determine your system balance.

With the advent of the computer-aided management systems, we find that there is a tendency to develop extremely sophisticated systems for cost collection purpose, and the handling of the business functions, payroll, purchasing, etc. The management functions that we worried about 15 years ago—policy, organization, evaluation and analysis, and budgeting—have tended to be sidelined. The profile, therefore, tends to look like a curve of normal distribution turned 90 degrees.

As we might surmise, if you cannot hang a computer on your program, or indicate in your position description that your work depends on a computer, you are not "in." For years the way to succeed was to develop new organization charts, new position descriptions, new policies and programs, and fight for control of the budget, or set up management analysis and review functions. In those days, the management opportunist fought a battle of words. Today the objective is to quantify. If you can manipulate numbers your road to success is open.

Most of you would rightfully agree that the case has been overstated by the descriptions just given. All of us who have been observing the management of government enterprises for any length of time recognize that there is a constant pendulum effect in management direction. Fortunately for most operations, the motion is in the center position twice for each time it is at the left or right position of the swing. If we could go from left to right without passing through the middle ground, most of our management systems would be chaotic.

This desire to quantify and rationalize every decision has merit. Hardly anyone would want to get up in front of his peers and present the case for irrationality as a mode of operation. In our approach to rationalization of decision-making, we have to make sure that we recognize that we are working in a total system, and that optimization of a subsystem may defeat our major system objectives.

For example, much of our current stress on numbers is connected with cost control. Cost control was developed in an industrial environment, where profitability could generally be measured. The impact of cost control had an ultimate profit measure in most instances. When we look at the public enterprise organizations we often find that cost control can have some rather negative effects. Our system of management does not provide an ability to determine the impacts of cost reduction across the total system. Let us examine some typical cases where cost control may be detrimental to the overall program, because our system is not geared to the profit motive.

In highway maintenance, we have in many instances two ways of accomplishing our work. We can do it with highway road crews, or we can contract for the work. If we are going to rationalize our decision, most of us would agree that we should do it by the most efficient and economic method. To make the decision, however, our accounting system must provide us with full information on the cost of our direct labor, fringe benefits, overhead for supervision, equipment costs including maintenance and repair with its own overhead burdens, equipment depreciation, and a few others. To the contractor's bid we must include the cost of contract preparation, administration, inspection, billing, and a pro rata share of legal costs for defending contract claims. At this point in time we might be in a position to make an evaluation on a cost basis. The story, as we well recognize, is not complete, however. There are other considerations, intangibles for the point of this particular maintenance job decision. We have to consider whether we have work for the people on our payroll, the impact of the reduction of in-house workload on our budget for next year, perhaps even the impact on our own job. The decision is patently one which involves more than pure costs. For example, depreciation has little actual meaning because we neither have to write off capital assets, nor can we declare depreciation as expense in a tax deduction situation. If we reduce our manpower usage in-house we might lose the numbers for next year when we will need the maintenance people.

In our efforts to control costs, many of us have to rely on central purchasing authorities. They operate on a pure cost basis in most instances. They buy at the cheapest price, sometimes with quality lacking. The fact that our equipment is deadlined for a five dollar part, which they are buying at the lowest price regardless of delivery time, is of no consequence to them in their particular attempt to optimize by buying at the lowest price.

With the pendulum swing that occurs when managers stress one program after another, lower management's attention often gets directed too deeply to one facet of the management system. One of my respected associates called this the "White Knight" syndrome. The White Knights pick up the current fad and charge off after much fanfare to win the current crusade. Meanwhile, back at the castle, the crops go untended, the drawbridge is not maintained and gets stuck, and the castle is overrun by bandits. When the Knight gets home he finds the whole place has gone to pot during his absence. The Knight may have gotten a medal for the crusade, but when the King comes around to collect the taxes, he better be off on another crusade.

Each of us has been exposed to this type of decision-making. Each of these problems is generally the result of not having a balanced management system.

We feel that the only way to get the balanced management system is to evaluate the strengths and weaknesses of your current system. The profile may be of some help in this area. The next step is to pick some of your people who know your current system, but are dissatisfied with its performance, and pull them out of the mainstream. Let them start with determining your objectives and defining your system. Identify the system components, and define the relationships and interactions between these components. If you interface with others, as we do in maintenance, we have to look at the whole real property cycle from planning to disposal. Define the problems or conflicts that are involved in the system, and then, and only then, try to apply technology to the development of alternative solutions. There are too many tools or techniques available to take the approach of pulling one off the shelf and trying to force it into a totally different environment. The technique may have worked in the state next door, and solved many problems. It may not work in your system as effectively, or it may even be a step backward.

It may sound like we are deprecating progress and a willingness to move ahead. Nothing could be further from the true situation. We do feel, however, that too often in our efforts for improving our systems we have not looked at the forest hard enough because of the magnitude of the problem, and instead start worrying about the individual trees.

THE UNANSWERED QUESTIONS

The current political fad is to point out problems, not solutions. It appears to be fairly successful so there is no reason why we in maintenance should not avail ourselves of this new technique. Problems are my bread and butter. I would prefer to solve them, if they are real problems, rather than talk about them, but one must start the definition phase before solution can occur.

Most of us would agree that we do not as yet have the best management structure for our highway system. It works, but there are often questions that we cannot begin to rationalize.

Our objective in maintenance is fairly simple. Maintain what they build. Do we have a reliable way of accumulating our costs so that the designers can look at the total cost of a highway from both a capital and operating standpoint? Are there re-

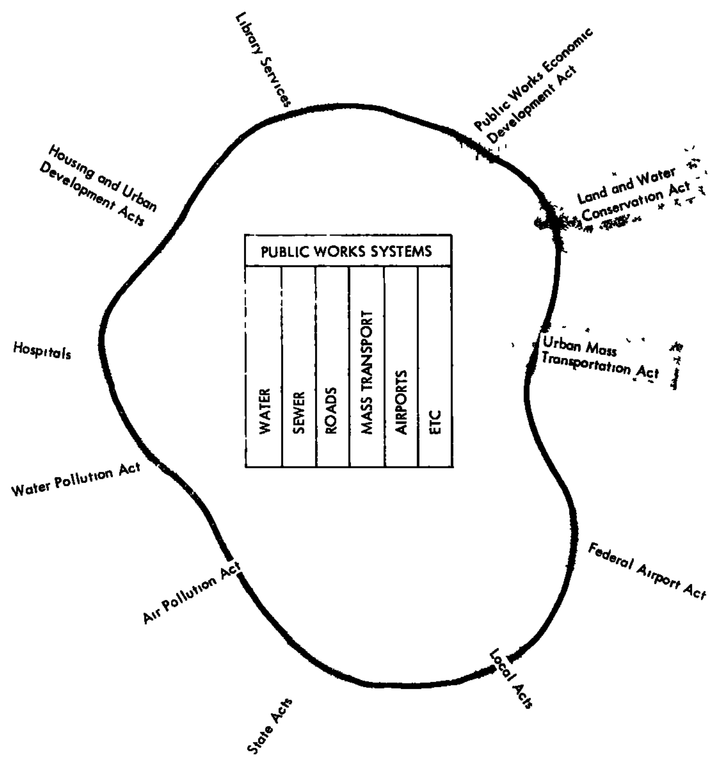

Figure 8. Existing patterns of laws that tend to foster vertical systems of planning, engineering, and construction.

strictions on our operations because of funding situations that force us into illogical decisions because we must follow the money chain? Figure 8 illustrates the problem of multiple funding for the urban environment. Similar problems exist in the maintenance area, and it is often difficult, if not impossible, to plan our work and operate effectively. Through arbitrary rules we have labor money, material money, and contract money. When we try to combine these pots of money we are often unable to make the choices that are rational because of the arbitrary allocation and control process. After much observation and some practical experience the use of a flexible budgeting system, such as an enterprise fund, has merit. If we got one kind of dollar to buy maintenance based on some form of output evaluation, then the day-by-day decisions on make or buy would be far simpler, and our cost collection systems more meaningful. There are many more questions such as these in the area of the management structure, but time does not permit discussion.

In studying the interrelationships within the highway system, one major problem involves getting adequate feedback to the design side of the house. In our attempt to maintain autonomy of the maintenance function have we destroyed our relationships with the designer? The following kinds of situations leave me to question how well this communication system is working. A picture appeared in the New York Times which showed a massive interchange proposed for one of the serious traffic bottlenecks in New York City. How much consideration will be given to maintenance in the design of that structure? What are they going to do with the snow? Are there maintenance turn-offs so that equipment will not block the flow? What was done to prevent deterioration from deicing materials? The designers may have the right answers to the kinds of problems that you and I in the maintenance world might ask, but do they in this case? Some things that I have spotted in the past month in California, New York, Colorado, Virginia, and Maryland make me want to question this premise.

With the current demand for protection on superhighways, guardrails are being installed at a tremendous rate—most of them in grassy areas. We have bridge abutments completely surrounded by guardrails, with no way except to lift the equipment over the rail or use hand tools to cut the grass. The guardrails are in most instances too low for anything but a sickle bar to pass underneath. If we are to maintain appearance we are going to be forced to hand cut around each of the guardrail supports, and also, the number of new signs that are being installed. It might be cheaper to put plastic collars around the posts, killing the grass to make it possible to use machine equipment.

The beautification program is already recognized as an additional drain on maintenance funds. But in a water short state is it rational to put in sprinkler systems at road interchanges so that we can grow flowers and shrubs—particularly when the interchange is surrounded by industrial and shoddy commercial ventures?

With our subspecialization of design, construction, and maintenance within a highway system, have we killed our ability to communicate effectively? Can we build our information system to overcome this difficulty?

In summary, I have attempted to describe the use of systems analysis in the maintenance management environment, indicated some of the general tools that I feel might be helpful in your analysis, and suggested some unanswered questions that make me feel that there is still a need for an in-depth look across the board into highway maintenance management systems.