On the Concept of Total Highway Management

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The need for a total highway management system is defined in this paper. A highway system serves a set of objectives, such as provision of an adequate level of service, preservation of the facility condition, safety, economic development, and others. It consists of a number of physical facilities, such as pavements, bridges, roadside elements, and traffic control devices. The system is managed through operational functions of a highway agency, such as planning, design, construction, maintenance, and so on. The highway system can thus be envisioned in terms of a three-dimensional matrix of objectives, facilities, and functions, all of which interact with each other. The current trend of developing separate management systems for pavements, bridges, and maintenance activities is a piecemeal approach, because it ignores the needs of the total system. Consequently, many current systems are either conflicting or involve duplication, or both. Instead, individual management subsystems, such as pavement management, bridge management, and maintenance management, should be developed in proper coordination with each other and with a clear understanding of the requirements of the total system. With the rapidly developing new information and communication technologies, there is an opportunity for organizing a total highway system that can assist in managing highway facilities in a highly efficient and productive manner.

The use of a systems approach to the management of highway facilities has gained much momentum since the 1960s when the need for systematic management of highway pavements was emphasized (*1–3*). Highway facilities include pavements, bridges, traffic control devices and structures, and roadside elements. These facilities must constantly be maintained or upgraded to cope with (a) automobile and truck traffic increase associated with growth in population and economic activity; (b) additional access roads required for new development; (c) higher quality and standard requirements in terms of travel comfort, safety, traveling speed, and environmental concerns; and (d) continuous deterioration and wearing out of the facilities. Besides planning, design, and construction, the major activities of a highway agency, therefore, also include maintenance, upgrading, rehabilitation, and reconstruction of highway facilities.

In an era of limited resources, it is not possible to implement all required activities to satisfy highway needs. An optimal selection of these activities has to be programmed and executed. Thus, a systems management tool is required to identify the best mix of activities that will achieve an acceptable level of system performance now and in the future.

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Significant research and implementation efforts have been made by highway agencies in the last two decades in the area of pavement management. In contrast, management of other highway facilities has not received the attention it deserves. It is clear that research and implementation priority should be assigned to areas in which highest returns or savings could be realized, however, such work must be carried out toward the achievement of optimal management of the total highway system. An optimal solution derived for a subsystem may not be the best strategy for the entire highway system.

In the light of tremendous interest in improving the expertise and technology in managing highway pavements, as evidenced in the current emphasis on research related to pavement materials and long-term performance of pavements (*4*), it is the intent of the authors in this paper to stress the importance of the concept of total highway facility management and the need for establishing a framework within which various management subsystems can be developed to enhance the effectiveness and efficiency of the entire highway system.

ELEMENTS OF A HIGHWAY MANAGEMENT SYSTEM

A comprehensive highway management system can be considered in terms of a three-dimensional matrix structure. The three dimensions are the highway facility dimension, operational function dimension, and system objective dimension. Table 1 lists the possible elements in each of the three dimensions.

The three-dimensional matrix structure indicates that a highway agency has a number of facilities in the highway system. The objectives of the agency are primarily related to cost-effective delivery of highway services. In this effort, the organizational framework of the agency is divided into a group of functions. Each facility in the system requires all of the management functions, and through planning, design, construction and other functions associated with the facilities in the system, the overall system objectives are fulfilled. If one chooses to look at a particular function (for example, planning), it is necessary to establish proper coordination among all the facilities in the planning process in order to contribute to the achievement of the objectives. Similarly, with regard to any one of the objectives, an optimal highway management system will have it satisfied through all the functions for any of the facilities. These interacting characteristics of the highway management system are schematically depicted in Figure 1.

TABLE 1 ELEMENTS OF HIGHWAY SYSTEM DIMENSIONS

Dimension	Highway Facility	Operational Function	System Objective
Elements	1. Pavement 2. Bridge 3. Roadside 4. Traffic control devices	1. Planning 2. Design 3. Construction 4. Condition evaluation 5. Maintenance 6. Improvement 7. Data management	1. Service 2. Condition 3. Safety 4. Cost 5. Socioeconomic factors 6. Energy

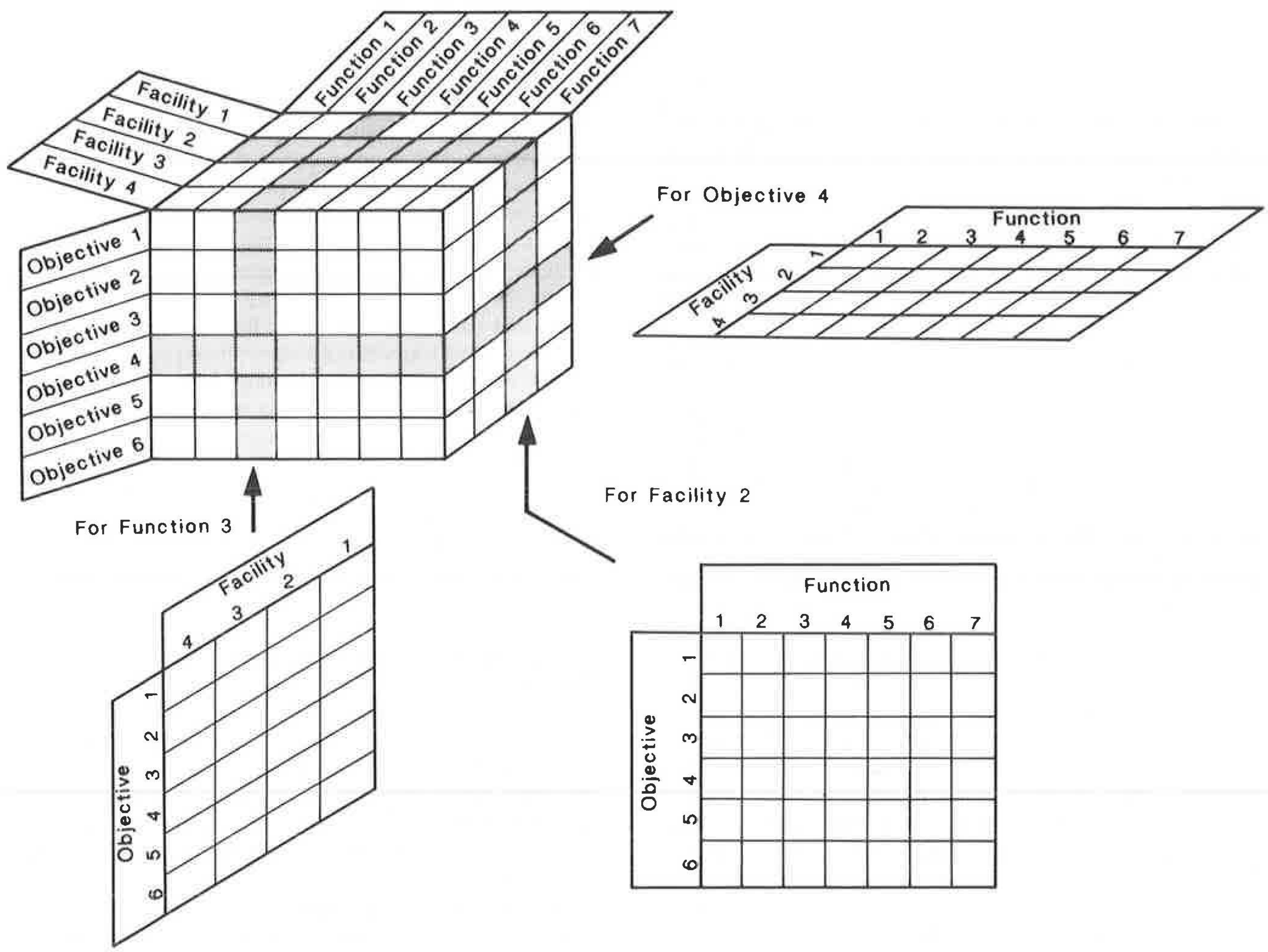

FIGURE 1 Three-dimensional matrix structure of highway management system.

Highway Facility Elements

A highway system has a number of physical facilities. Pavements, bridges, roadside elements, and traffic control devices are all different in their service characteristics. Pavements and bridges are to carry traffic and traffic control devices are for traffic safety and guidance, whereas roadside elements are for convenience and aesthetics. Pavements rarely fail catastrophically, but bridges may collapse with potential loss of life. On the other hand, although pavements and bridges deteriorate progressively with age, traffic control devices and some roadside elements may be put out of service instantly by traffic accidents or mechanical faults. Activities performed on pavement and bridges unavoidably affect flows of traffic and cause delay to users. Activities related to roadside elements and some traffic control devices may, however, be managed without a major traffic disruption.

The differences between different highway facilities are also reflected in their life-cycle spans. Table 2 shows the range of life cycles for each facility type. The varied life-cycle spans among the facilities along with the difference in the type of services provided make it necessary for highway agencies to adopt different management strategies for each facility.

Because of such differences in service characteristics, it is a common practice in field operation to consider management of different facilities independently. The classification of highway facilities, however, does not end here. Within the broad category of four major highway facilities identified in Figure 1, it is often necessary to subdivide them further into types of similar physical and service features. Table 3 gives examples of facility element types commonly found in a highway network.

The significant implication of the multielement structure of highway facilities is that each subsystem would compete for funds and other resources such as manpower, equipment, and materials within the same highway organization. The overall effectiveness of a highway system depends on the levels of service provided by the individual subsystems. Because resources are limited, an optimal allocation among the various subsystems must be formulated. Because each facility element has a different impact toward achieving various objectives of the total highway system, the relative importance of these facility elements needs to be assessed for a logical resource allocation.

Although there exist many management subsystems by facility element types, and they may differ in technical details and emphases, one must recognize that the sequence of functional activities in each and the objectives for all these subsystems remain the same. Discussions on these two aspects of management systems follow.

Operational Functions

It is clear from the matrix structure, shown in Figure 1 and Table 1, that in the management of each highway facility element, the following operational functions are involved: planning, design, construction, condition evaluation, maintenance, improvement, and data management. Some of these functions may be combined in some agencies, and some of them may be further subdivided. The basic functional aspects, however, remain the same. The concept of systems approach in carrying out these highway operational functions, in the area of highway pavement management in particular, has been frequently addressed in the literature since the 1960s (*2,3,6,7*).

Figure 2 shows the functional activities involved in a typical management system of a highway facility. The planning phase deals with the preparation of capital expenditure programs for highways as a whole based on overall road needs including facility expansion and system preservation. The planning phase covers demand analysis and estimation of facility needs to accommodate the current and future traffic. There are many priority programming methods available for selecting highway capital projects, although project selections are often made on the basis of historical trends or regional needs estimates.

The design phase is a subsystem that generates alternative facility configurations, analyzes these alternatives, and evaluates and selects the optimal configuration. Construction involves the management of budget, time, people, equipment, and materials to transform designs into physical realities. The major concerns of the construction phase are preparation of specifications and contract documents, scheduling of construction activities, control of costs and quality of construction, and monitoring of work progress.

The next three functional activities, condition evaluation, maintenance, and improvement, are the main focus of most facility management systems. Condition evaluation includes facility condition survey, analysis and prediction of facility performance, and decision analysis on actions required. A facility condition would include not only the physical condition of the facility, but also the traffic service. The decision analysis is usually a trade-off analysis to select facilities for either the maintenance or improvement program. An improvement program would include both condition improvement, such as resurfacing of pavements and bridge decks, and facility expansion, such as widening of roads and bridges. Often, the function of condition evaluation is included in the planning function.

AASHTO (*8*) defines highway maintenance as a program to preserve and repair a system of roadways with its elements to its designed or accepted configuration. Highway maintenance activities are distinguished from improvement programs by either the scale of operation in terms of the extent of work performed (*8*) or by the mode of operation according to whether the work is performed by highway agency maintenance crew or by contractors (*9*).

Data management is a vital link in any management system. It covers acquisition and compilation of data, organization and updating of data bases, and provision of efficient retrieval of relevant data. Figure 2 also illustrates the important role of data management in coordinating various functional activities within a subsystem, as well as those activities in other subsystems, through a continuous transfer and exchange of information.

TABLE 2 LIFE CYCLE SPANS OF HIGHWAY FACILITIES (*5*)

Highway Facility	Life Cycle Span (yr)
1. Pavements	
Flexible	15–20
Rigid	35–40
2. Bridges	25–50
3. Traffic Control	
Signs	1–3
Pavement markings	1–3
4. Roadside	
Drainage structures	25–50
Right of way	100–150

TABLE 3 LIST OF HIGHWAY FACILITY TYPES

Pavement	Bridge	Roadside Facility	Traffic Control Devices
1. Flexible	1. Concrete	1. Guardrails/barriers	1. Signs
2. Rigid	2. Steel	2. Utility poles	2. Pavement markings
3. Composite	3. Timber	3. Drainage	3. Traffic lights
4. Interlocking	4. Other	4. Rest areas	
5. Unpaved roads		5. Rights of way	

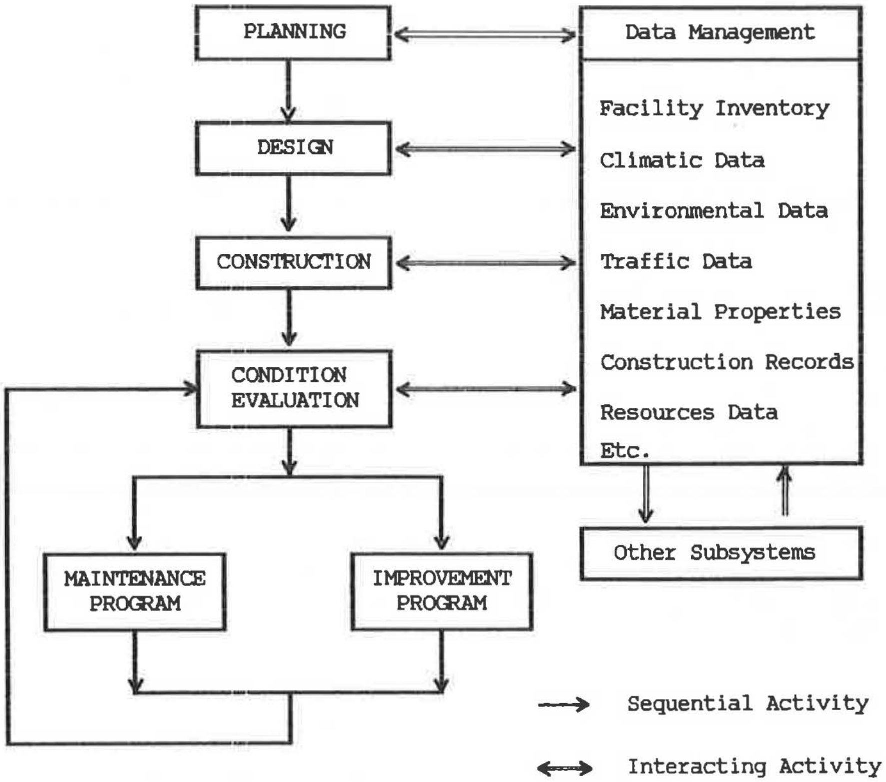

FIGURE 2 Activities in the management system of a highway facility.

System Objectives

The highway management process is a multiple-objective problem. As listed in Table 1, the major objectives may include the following: provision of an adequate level-of-service for traffic, preservation of facility condition at or above a desired level, achievement of a high level of traffic safety, minimization of agency and user costs, maximization of socioeconomic benefits, and minimization of the use of environmental and energy resources. The ultimate goal of a highway program is to satisfy these objectives as closely as possible within the constraints of available budgets.

To facilitate highway management programming purpose, the system objectives can be assessed quantitatively by means of highway performance indicators. In Table 4 are listed, for various highway facilities, a set of performance indicators that can be considered for each system objective. Performance indicators are useful in a number of ways. Because they provide indications of the degree of fulfillment of system objectives, priority ranking of facilities can be established based on the relative values of performance indicators. They can also be used for comparison of the effectiveness or adequacy of alternative design schemes, or maintenance and improvement strategies. Last but not least, they can be easily incorporated into a mathematical optimization programming model for highway management (*11,16,17*).

As in any complex multiple-objective system, contradictions exist in fulfilling the various system objectives of highway management. For instance, maximizing traffic volume/capacity ratio necessarily brings about an increase in noise and air pollution and accelerates the physical deterioration of pavements and bridges. The provision of wider lanes and shoulders improves highway safety and traffic flow, but it results in a corresponding increase in capital investment and an increase in the consumption of land and environmental resources. These examples illustrate the nature of the highway system management problem. It is not possible to achieve a complete fulfillment of all objectives simultaneously. Instead, one has to strive for a suitable mix of actions that will ensure the best achievement of system objectives without violating any constraint.

Requirements of Highway Management Systems

The primary function of a highway management system is to serve as a decision making tool for highway agencies. Toward this end, the system must satisfy the following criteria:

- *Comprehensiveness:* A highway management system must address all major issues affecting the performance of highways. Elements in the three dimensions of the matrix structure of highway systems must be considered. Because of the multiple-objective nature of the system, solutions developed for individual subsystems or for a single objective are unlikely to be globally optimal for the total highway system.
- *Flexibility:* The management system must be flexible to accommodate variations in different regions of a highway network. Such variations include functional classes of highways, unit costs of highway activities, priorities among system objectives, preferences over different highway functional activities, differences in climatic and environmental conditions, and so on.
- *Applicability:* In order to be useful to top managers at different levels, the management system must be tailored in

TABLE 4 PERFORMANCE INDICATORS FOR HIGHWAY SYSTEM OBJECTIVES

Facility \ Objective	Service	Condition	Safety	Cost	Socio-Economic Factors	Energy
Pavement	1. Volume/Capacity ratio 2. Travel speed [10,11]	1. Structural capacity 2. Pavement distress severity 3. Serviceability [3,12]	1. Skid resistance 2. Geometric alignments 3. Lane width 4. Shoulder width Occurrences of accidents [10,11,12]	1. Agency costs 2. User vehicle operating costs [3,12]	1. Noise level 2. Air pollution level 3. Visual quality [10,11,13]	1. Fuel consumption [10,11]
Bridge	1. Clear deck width 2. Vertical clearance 3. Traffic speed [14,15]	1. Load capacity 2. Remaining service life 3. Deck, superstructure and substructure deterioration index [14,15]	1. Load capacity 2. Clear deck width 3. Occurrences of accidents [14,15]	1. Agency costs 2. User costs [14]	1. Travel time savings 2. Visual quality 3. Saving in accident costs [13,14]	1. Fuel consumption [10,11]
Roadside Facility	1. Travel speed 2. Clear roadway width [20,21,22]	1. Structural adequacy 2. Deflection/ Displacement 3. Ditch erosion [20,21]	1. Impact performance 2. Occupant risk 3. Roadside slope [20,21,22]	1. Agency costs 2. User costs [21,23]	1. Saving in accident costs 2. Visual quality [20,22]	1. Fuel consumption [10,11]
Traffic Control Devices	1. Volume/Capacity ratio 2. Delay time [18]	1. Visibility 2. Physical deterioration [18,19]	1. Sight distance 2. Luminance [18,19]	1. Agency costs 2. User costs [18]	1. Travel time delay 2. Fuel waste 3. Pollution 4. Driver satisfaction [13,18]	1. Fuel consumption [18]

accordance with the organizational structure of an agency to ensure continuity in management operations.

- *Sensitivity:* To be a good strategic decision making aid, the management system must be capable of analyzing the impacts of changing macroeconomic factors such as inflation, energy price and availability, changes in automobile and truck characteristics, and changes in type and intensity of traffic loadings. It should also be capable of analyzing the implications of different highway policy decisions such as relative emphases of various system objectives among and within highway classes, performance standards for various highway classes, and priorities for different activities.

LIMITATIONS OF EXISTING MANAGEMENT SYSTEMS

The concept of total highway system management provides a useful yardstick to assess the adequacy of existing management systems for highways. Major areas of deficiency of common management systems in use today are highlighted and discussed in the following sections. Because pavement management systems are the most developed of all highway facility management systems, they are used to illustrate the points presented.

Lack of Comprehensiveness

Listed in Table 5 are the results of a literature review showing representative work reported in the last two decades on programming procedures used in management of highway pavements. A great majority of the procedures produced solutions that optimized only one single system objective. Most of these single-objective procedures sought to optimize pavement conditions under the constraints of budget and other resource constraints; others selected projects to minimize agency costs or maximize user benefits.

TABLE 5 PROGRAMMING PROCEDURES IN HIGHWAY PAVEMENT MANAGEMENT

Study	Objectives	Techniques	Application
1. Gulbrandsen 1967 [26]	Single	Dynamic Programming	Resource Allocation
2. Lemer & Moavenzadeh 1970 [29]	Single	Repeated Trials	Project Level Programming
3. Hutchinson 1972 [27]	Single	Benefit-Cost Analysis	Investment Programming
4. TRANS 1973 [17]	Multiple	Investment Return Analysis	Resource Allocation
5. Chapman 1973 [25]	Single	Dynamic Programming	Construction Investment
6. Rankin 1973 [32]	Single	Unconstrained Technique	Funds Allocation
7. Carstens 1973 [24]	Single	Dynamic Programming	Project Selection
8. Lu & Lytton 1976 [30]	Single	Integer Programming	Rehabilitation & Maintenance
9. Knox et al. 1976 [28]	Multiple	Judgmental	Improvement Programming
10. HIAP 1976 [16]	Multiple	Ranking by Cost-Effectiveness	Investment Programming
11. Robinson 1976 [31]	Single	Direct Estimation	Project Evaluation
12. TRRL 1976 [34]	Single	Cost-Benefit Analysis	Project Evaluation
13. PIAP 1978 [33]	Multiple	Ranking by Cost-Effectiveness	Highway System Programming
14. Mahoney et al. 1978 [35]	Single	Integer Programming	Rehabilitation & Maintenance
15. Zegeer et al. 1981 [36]	Multiple	Dynamic Programming	Resurfacing Projects Selection
16. Muthusubramanyam 1982 [11]	Multiple	Goal Programming	Maintenance & Rehabilitation
17. Colucci-Rios 1984 [37]	Single	Integer Programming	Maintenance & Rehabilitation
18. Kher and Cook 1985 [38]	Single	Linear Programming	Rehabilitation Investment
19. Shahin et al. 1985 [39]	Single	Incremental Benefit-Cost Technique	Maintenance & Rehabilitation
20. Markow et al. 1987 [40]	Single	Dynamic Control Theory	Maintenance & Rehabilitation
21. Fwa et al. 1988 [41]	Single	Integer Programming	Highway Maintenance
22. Feighan et al. 1988 [42]	Single	Markov Chain Dynamic Programming	Pavement Maintenance & Rehabilitation

Of the few approaches that considered multiple objectives, however, none had included a broad range of objectives mentioned in Table 1. The TRANS model (*17*) evaluated user and external impacts, whereas the Highway Investment Analysis Package (HIAP) (*16*) maximized either user benefits or one of several accident reduction measures. Knox et al. (*28*) described the highway programming and techniques developed in Illinois. Although recognizing the multiple objective and dynamic nature of the problem, the methodology is essentially an exhaustive listing of alternative solutions, and specific projects were selected based on interactive judgments of district and central officials. Zegeer et al. (*36*) considered user and agency costs and energy and socioeconomic factors in a dynamic programming model for resurfacing project selection.

A major contribution in this field is the Performance Investment Analysis Process (PIAP) (*33*), which was developed for estimating existing and future highway system performance and for determining appropriate investment levels and program priorities. Each highway section is examined for a deficiency in a prioritized order—new location, operating speed, traffic volume/capacity ratio, lane or approach width, alignment, and surface type and condition—until one deficiency is found. Only one deficiency is determined for each section. A ranking process is then employed to select improvement projects under a given investment level. Mathematical optimization was not used in the analysis.

An example of the multiobjective approach was presented by Muthusubramanyam (*11*) who developed a goal programming technique to analyze the impacts of highway improvement and maintenance policies. The following seven highway activities were considered: reconstruction, major widening, minor widening, restoration, resurfacing, safety and traffic engineering improvements, and routine maintenance. Five system objectives were considered for simultaneous optimization. They were pavement condition, level-of-service for traffic, safety, energy, and air pollution. The approach, although applied only to pavement related activities, can be extended to cover more activities and system objectives, if desired.

A literature review indicates that there is a general lack of comprehensiveness in the management systems currently in use. There is a high risk of accepting suboptimal solutions in management systems that do not address adequately the major issues identified in Table 1. For instance, most pavement management systems do not consider level-of-service for traffic and user costs in their analyses. Because pavement condition is the measure of effectiveness in most pavement management systems, a highway section in need of both widening and resurfacing would be considered only for resurfacing. However, a better solution would be to widen and resurface the section, leading to better flow of traffic, reduced congestion, lower vehicle operating costs, and likely slower rate of pavement deterioration.

Lack of Systems Coordination

Most of the current management systems have been developed in virtual isolation from each other. Highway agencies adopt the practical approach of developing management subsystems within the constraint of their organizational structures. Thus, the purpose of management systems is to serve the needs of a specific division or unit rather than the overall objectives of the agency. Unfortunately, this has led to a lack of coordination and often to a duplication of efforts. Figure 3 illustrates a case of poor system coordination commonly found in practice.

A pavement management system (PMS) encompasses various functional activities on pavements, including their maintenance. A maintenance management system (MMS) involves managing maintenance of all highway facility elements including pavements. Both PMS and MMS therefore have, as a component of their system, a pavement maintenance management system (PMMS), a term commonly used in the literature. Problems arise in the following areas:

- The thrust of MMSs is resource management (labor, material, and equipment) with the primary measure of effectiveness being work productivity or accomplishments per day. On the other hand, PMSs are directed mainly toward facility management with the primary objective being the improvement of pavement condition. Although PMSs are envisioned to encompass all activities related to pavements, most common elements are 4R-type improvement projects involving reconstruction, rehabilitation, restoration, and resurfacing.
- Pavement improvement and maintenance activities are performed separately and by different units in a highway agency. Although improvement activities may involve planning and construction divisions, maintenance activities are planned and implementated by maintenance divisions in most highway agencies. There is little exchange of information between these two functions, often causing expensive duplication of efforts. For example, some highway sections may be resurfaced only a few months after receiving such expensive maintenance work as seal coating. A coordinated program could save substantial amounts of both agency and user costs.
- The forms of pavement condition data required for planning of pavement improvement and maintenance works are quite different (*43,44*). Aggregate pavement performance data are useful for trade-off analyses between the two types of activities and are appropriate for improvement planning. They are, however, not adequate for programming and scheduling of routine maintenance activities. Many PMSs specify condition surveys without giving due consideration to the data requirements for maintenance management.

The problems of poor coordination are not unique to the area of pavement management. It is easy to visualize by looking at the illustration in Figure 3 that similar conflicts can exist for other facility management systems if proper coordination is not ensured.

Relationships of Functional Activities

The primary purpose of a highway agency is to provide a quality service at a reasonable cost to the users and taxpayers. In this effort, the common goal of all individual organizational units and functional activities within an agency is to see that the objectives of the agency are fulfilled. Consequently, an important dimension of the total highway management concept is to emphasize the interrelationships among different functional activities. A common weakness of today's highway management approaches is a sort of "Balkanization," or fragmentation, of efforts. In addition, there is often a sense of

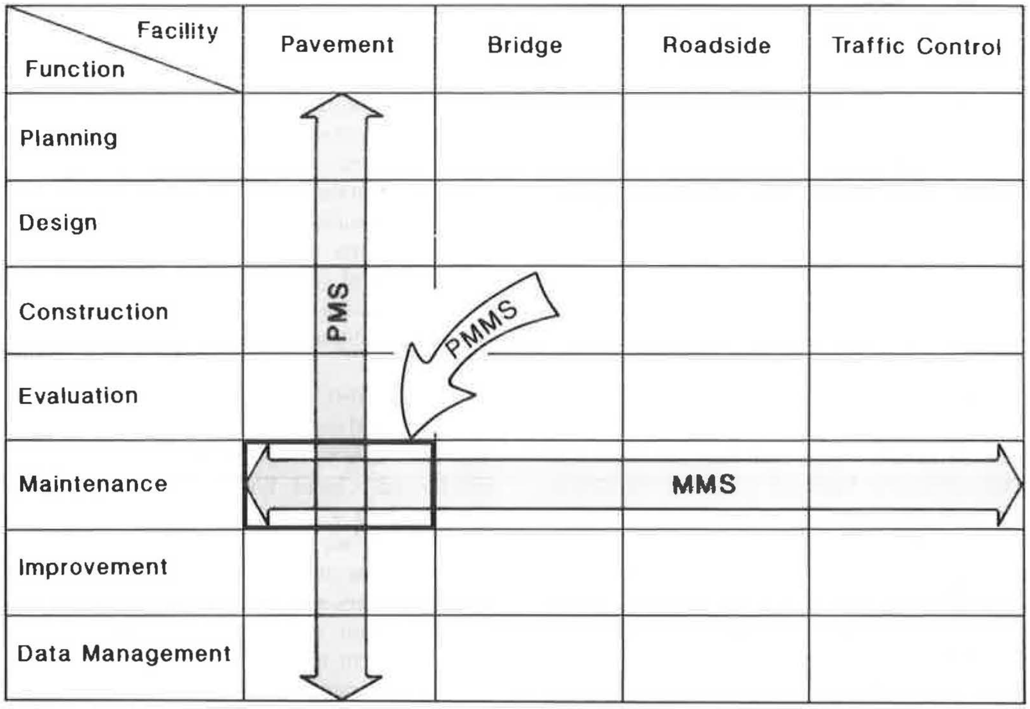

FIGURE 3 Relationships between a pavement management system (PMS), pavement maintenance management system (PMMS), and maintenance management system (MMS).

"territorial sovereignty" among the organizational units performing such functions as planning, design, construction, maintenance, and so on. The loyalty of individuals within a particular unit or division often does not reach beyond the limits of that unit. The development and implementation of specific management systems along the work functions of individual organizational units foster and institutionalize the tendencies toward "Balkanization" and territorial claims. This situation has become apparent at several state highway agencies where efforts have been made to implement pavement management systems. A strong resistance has been offered by maintenance and other divisions against the development of a common data base in the fear of being "taken over." In this connection, it must be pointed out that there is an utter lack of research information on such items as the effect of maintenance activities on facility performance and service lives. Consequently, many activities are performed without any clear idea about their usefulness or effectiveness.

A life-cycle cost-analysis approach in the management of highway pavements has been proposed by Markow (*45*). Life-cycle cost analyses, if properly formulated, can help one to understand the roles of various functional activities, such as maintenance and improvement, in influencing the performance of highway pavements. The same concept is also applicable to the management of other highway facilities. Much research and implementation work is, however, still needed in this direction.

Quality of Data Management

The importance of data management has been depicted in the flowchart in Figure 2. One of the major challenges to highway agencies is the establishment and upkeep of the flow of information between various subsystems of the highway system. Information flow channels should allow various subsystem decision makers access to all information collected and enable them to analyze strategies in the area of their responsibility. The information presented in Figure 3 implies that an efficient data management system must allow free flow of information in both vertical and horizontal directions of the matrix structure.

Lack of relevant information greatly impairs the proper functioning of a highway management system. This is a common problem with pavement maintenance. Maintenance planners often receive little information on construction or design, although such data have a direct impact on formulation of maintenance programs and policies. Many maintenance planners also are not informed well in advance of pavement rehabilitation decisions in order to make necessary adjustments to their maintenance programs.

There appear to be two schools of thought in terms of data management systems. Many highway agencies are developing comprehensive data systems on large mainframe computers. Such large systems have been found costly and difficult to maintain (*46*). With the emergence of microcomputers, the concept of integrated information systems is gaining acceptance by more and more highway agencies (*46,47*). Whatever the system adopted, the following basic requirements have to be fulfilled (*48*): (a) a common reference for all subsystems, (b) immediate accessibility to users of different management levels, and (c) easy data updating at regular intervals.

Organizational Structure

Most highway agencies have an organizational structure in which functions such as planning, design, construction, and others are centrally managed with districts and subdistricts performing field operations of construction and maintenance. In recent years, there have been some agencies that have decentralized much of the decision making process with districts taking direct responsibilities for selecting construction, improvement, and maintenance projects. In either case, the potentials offered by the information and communication technologies have not been explored and the effective application of management systems has remained far from being accomplished. To accommodate installation of highway management systems, the management structure and operational system of highway agencies may need to be revised.

Byrd and Sinha (*43*) proposed two alternative organizational structures that could enhance the integration of PMS and MMS in a highway management system. The first alternative is a separate organizational unit that is responsible for data management, program planning, and scheduling of all pavement maintenance and improvement activities. The other alternative is the establishment of a coordinating committee that serves as the advisory group for all pavement functional activities. This concept can be extended to fit the operational requirements of a highway management system into any existing highway organization.

Linkage to Pricing and Taxation

An important function of a highway management system can be to monitor the cost responsibilities of various user groups in terms of damages caused and system use. Appropriate information on facility performance and traffic loadings can assist in determining proper pricing and taxation policies. At present, highway cost-allocation studies are occasionally undertaken by state highway agencies, as a part of a legislative move to raise highway user fees. Instead, a periodic analysis of cost responsibilities and revenue contributions of various vehicle groups can be routinely performed as a part of highway management systems.

CONCLUSION

About two decades ago, MMSs were developed primarily to manage resources for highway routine maintenance. PMSs have since then been developed and implemented in some states and local agencies to make decisions regarding pavement resurfacing and other improvement activities. At present, much work is under way in the area of bridge management systems. All of these management systems have unique data requirements and specific purposes to serve. The implementation of these separate systems is a piecemeal approach that does not optimally serve an agency's management objectives.

Both MMSs and PMSs have so far served well their intended specific purposes. However, the need for consideration of a total highway system management requires that individual subsystems be realigned. For example, MMSs must also consider the condition of pavement, structure, drainage, and other highway facility elements in addition to the management of labor, material, and equipment. At the same time, the preoccupation of PMSs with pavement and shoulder conditions must change to include such items as the traffic level-of-service so that decisions regarding surface improvements can be made in conjunction with facility expansion such as widening and lane additions. This is particularly important in view of the growing concern about congestion in many metropolitan corridors and the inability of the highway system to cope with traffic demands.

In the coming years, state highway agencies will have to face more and more the challenge of legislative scrutiny and accountability with respect to highway budgets. In this connection, it will be necessary for top highway managers to have quick access to facility management information systems. In addition, questions are being raised about the role of highways in economic development. This issue is becoming an important factor in highway budgeting decisions in many state legislatures. Consequently, highway managers must start to broaden their perspectives and take account of how the highway system serves the state and local economy and to what extent new investment can stimulate growth. Highway management systems, therefore, must also have the ability to incorporate economic potentials in investment decisions and, thus, would also serve as a tool for long-range planning.

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