CONFERENCE PROCEEDINGS 1

Third International Conference on Managing Pavements

Volume 3

San Antonio, Texas
May 22–26, 1994

Sponsored by

Transportation Research Board
Federal Highway Administration
Ontario Ministry of Transportation
American Association of State Highway and Transportation Officials
Texas Department of Transportation
International Society for Asphalt Pavements
American Concrete Pavement Association

NATIONAL ACADEMY PRESS
WASHINGTON, D.C. 1995

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

Conference Proceedings 1
ISSN 1073-1652
ISBN 0-309-05502-4

Subscriber Category
IIB pavement design, management, and performance

Transportation Research Board publications are available by ordering individual publications directly from the TRB Business Office or by annual subscription through organizational or individual affiliation with TRB. Affiliates and library subscribers are eligible for substantial discounts. For further information or to obtain a catalog of TRB publications in print, write to Transportation Research Board, Business Office, National Research Council, 2101 Constitution Avenue, N.W., Washington, D.C. 20418 (telephone 202-334-3214).

Printed in the United States of America

The conference was sponsored by the Transportation Research Board, the Federal Highway Administration of the U.S. Department of Transportation, the Ontario Ministry of Transportation, the American Association of State Highway and Transportation Officials, the Texas Department of Transportation, the International Society for Asphalt Pavements, and the American Concrete Pavement Association.

Contents

Message from the Conference Chairman

Ralph C.G. Haas, *University of Waterloo*

This is the third and final volume of the Proceedings of the Third International Conference on Managing Pavements. Volumes 1 and 2 included peer-reviewed papers presented at the conference and were distributed to attendees in San Antonio. This volume includes the opening and closing plenary session addresses, keynote presentations, several invited papers, and results of the various workshops.

A key feature of the Sunday before the conference opened was three tutorial sessions that are not included in the proceedings but are listed below:

- Predictive Tools, presented by Olga Pendleton, Texas A&M University, with Carl Monismith, University of California, Berkeley, as moderator and facilitator.
- Optimization Techniques, presented by Robert Lytton, Texas A&M University, with Per Ullidtz, Technical University of Denmark, as moderator and facilitator.
- Monitoring Road Condition and Traffic: Review of Current Options for Data Collection Methods and Equipment, presented by Waheed Uddin, University of Mississippi, and Perry Kent, Federal Highway Administration.

These tutorials were extremely well received; in fact, registration for them was oversubscribed. The contributions and efforts of the presenters and moderators are sincerely appreciated.

The exhibits were another key feature of the conference. A list of conference exhibitors appears in this volume.

Sincere thanks are also extended to the various sponsors listed, to the many individuals who worked to make the conference a success, and to the more than 500 registrants from 40 countries who actively participated in the technical program and social activities. A list of registrants appears in this volume.

Finally, heartfelt gratitude is extended to the steering committee for the conference, including the two cochairmen, not only for all their efforts but for their dedication to ensuring a successful conference. Biographical sketches of members of the conference steering committee appear in this volume.

Conference Objective, Background, and Themes

The objective of the Third International Conference on Managing Pavements was to enhance the effectiveness and efficiency of managing pavements for roads, streets, airfields, and other areas. The conference provided an opportunity for executives, practitioners, and researchers to share and evaluate recent experiences with pavement management systems. It addressed the benefits of implementation, the effects of support on decision making, advances in the state of the art and technology, and the need for future development.

Background

The road systems of the world represent a huge investment on the part of governments and taxpayers. There is widespread concern over the state of the road infrastructure. Despite indications of increased investment, it is clear that the funds available are unlikely to meet all of the needs of this sector in the long run. Wise investment decisions concerning the road system will be more crucial than ever to the future of highway transportation.

In recent years a number of pavement management systems and concepts have been developed to assist decision makers. The effectiveness and the extent of use or implementation of these systems still require substantial improvements. In large part this is due to financial, technical, organizational, and political factors. Yet effective pavement management remains a key to the future of roadway systems.

Themes

The conference addressed the following themes:

- Appropriate systems: Papers covered the development or enhancement of pavement management systems appropriate to the agency under consideration. Workshops were designed to enable small groups of participants to evaluate and discuss the priority issues from their perspectives.

• Implementation issues: Developments and implementation issues at the national, state and provincial, municipal, and local levels were presented. Innovations in implementation and marketing of maintenance and rehabilitation to decision makers were discussed.

• Institutional issues: Papers from several countries described institutional issues at national, state, and local levels. An educator's perspective was also included. Workshops enabled participants to identify ways of overcoming potential hurdles to implementation.

• Managing information: A full range of techniques and advice about how to use them were presented. A tutorial was offered for those who wished to gain firsthand experience.

• Analytical issues: The latest experience with performance prediction, optimization of benefits from scarce resources, and the weighing of user costs versus agency costs was covered in presentations and workshops. Two optional tutorials in predictive tools and optimization techniques were also available.

• New frontiers: This part of the conference provided information about emerging issues likely to affect pavement management.

Contents of Volumes 1 and 2

INSTITUTIONAL ISSUES IN PAVEMENT MANAGEMENT

NEW FRONTIERS

INNOVATIONS IN PMS IMPLEMENTATION

OPTIMIZATION

MUNICIPAL/LOCAL DEVELOPMENTS AND ISSUES IN PMS IMPLEMENTATION

BETTER DATA QUALITY MANAGEMENT

Welcome Address from the Federal Highway Administration

E. Dean Carlson, *Federal Highway Administration*

On behalf of the Federal Highway Administration (FHWA), I want to welcome you to the Third International Conference on Managing Pavements. It is indeed an honor to follow the success of the Ontario Ministry of Transportation, which hosted the first two conferences in Canada, by hosting this conference in the United States.

It is both significant and appropriate that 35 countries are represented at this conference. The United States believes in, supports, and participates in the international exchange of information and technology. FHWA demonstrates this commitment through our broad-based international office, our participation in the Pan-American Institute of Highways, our membership and active participation in the Permanent International Association of Road Congresses and our most recent tours of Europe to learn about asphalt and portland cement concrete pavement technology and contract administration techniques for quality enhancement.

In addition, the Pacific Rim TransTech Conference gave the United States the opportunity to exchange ideas on transportation technologies with Pacific Rim countries. The Strategic Highway Research Program transcends many international borders and will prove invaluable to highway engineers around the world. I believe this conference on pavement management will also make a valuable contribution to the international exchange of pavement management technology. The rapid changes of political structures around the world, such as the reunification of Germany and the change in the former Soviet Union, have put transportation professionals in what I hope is a gratifying position to work with one another, help one another, and strive toward the same goals in doing the best possible job of moving people and goods.

The first conference focused on teaching pavement management. The theme of the second conference was implementing pavement management. Today I want to emphasize the use of pavement management. To understand the many uses of a pavement management system (PMS), I will discuss it in relation to the Intermodal Surface Transportation Efficiency Act (ISTEA), the National Highway System (NHS), the North American Free Trade Agreement (NAFTA), and FHWA's new pavement management policy. I will also discuss the future of pavement management.

ISTEA, passed by Congress in 1991, includes many new provisions affecting the surface transportation industry in this country. ISTEA has changed the way FHWA goes about its business. For the past 30 years FHWA managed the federal highway program on a project-by-project basis. By and large, our engineers reviewed project designs and inspected individual construction projects. ISTEA has shifted FHWA from engineering individual projects to managing networks and programs.

The mechanism in ISTEA that provides for the shift is the requirement that all states establish management systems for pavements, bridges, congestion, safety, transit, and intermodal facilities. These management systems represent a commitment to invest wisely in our infrastructure programs and to continue to improve the quality and performance of our infrastructure facilities. As President Clinton recently said, "A well-functioning infrastructure is vital to sustained economic growth, to the quality of life in our communities, and to the protection of our environment and natural resources."

ISTEA requires each state to have a PMS that covers all federal-aid highways within the state. The states, local governments, and toll road authorities are the direct owners and users of these PMSs, but FHWA oversees their use in the context of the federal-aid program. A PMS approach brings to the table a condition-based assessment of the health of the federal-aid road network, coupled with the ability to perform life-cycle cost analysis. The PMS can produce sound engineering recommendations for decision makers to use in establishing a cost-effective and rational pavement preservation program. The systematic process of a PMS gives FHWA the assurance that federal funds are being invested wisely, and at the same time it maintains accountability.

A major component of ISTEA addresses the growing transportation needs of this country in the post-Interstate era: the NHS. The NHS is an integrated network of the most important roads and streets in the country supporting interstate and interregional travel and commerce. The NHS system will also link the most important ports, airports, intermodal transportation facilities, public transportation facilities, and national road systems in Canada and Mexico. This system consists of the Interstate system and other principal arterial routes, with a total length of approximately 159,000 mi. It is designed to maintain the pace of our economic growth, enhance the mobility of the American people, and help our nation thrive in the increasingly competitive global marketplace.

The federal emphasis, resources, and stewardship are concentrated on the NHS. This concentrated effort is intended to maintain and improve pavement conditions on the NHS through the use of PMSs. Since 75 percent of large truck travel takes place on the proposed NHS, this truly makes the NHS the economic lifeline of this nation. If the NHS achieves its goals, a significant side benefit will be the diversion of large trucks from the minor roads system, which will help preserve that system and prevent increased wear and tear.

Pavement management is also a tool for implementing NAFTA. The NHS, NAFTA, and PMSs are all interrelated. Truck traffic represents 80 percent of the freight moving between the United States and Mexico and 60 percent of the freight traffic between the United States and Canada. The NHS will serve all major international border crossings that connect to the Canadian and Mexican national networks. Under the terms of NAFTA, trade is expected to accelerate between Canada, the United States, and Mexico. The current estimate is that trade between the United States and Canada will increase 25 percent over the next 10 years. Trade between the United States and Mexico is expected to double over the same period. NAFTA, by virtue of the increased number of large trucks it will generate, will have a significant impact on the wear and tear of highway pavements.

State PMSs must be used to track and predict the location and magnitude of this increased truck traffic. We must assess the current load-carrying capacity of these crucial roads and then be prepared and equipped to provide the additional carrying capacity necessary to make these pavements operational. While we design the NHS and establish free trade with our neighboring countries, we as engineers and managers must make absolutely sure our pavements can do the job. PMSs give us the tools to help do that job.

Next I want to discuss quality. Whether we manufacture cars or provide pavements, our customers expect a quality product. We are obligated as public servants and professionals to give the taxpayers good pavements. The two things that damage pavements are loads and the environment. The quality of our pavement design, construction, rehabilitation, material, and preventive maintenance directly affect the rate of deterioration of our pavement. As quality increases, the rate of deterioration decreases. We can use our PMS data bases to evaluate the performance of our pavement network relative to the quality of our design, construction, and so forth.

Let's ask ourselves these basic questions:

- Is the actual life of our pavements reasonably close to the theoretical design life?
- How much additional life do we get when we invest in better paving materials?
- How much additional pavement life do we get when we increase the quality level of our construction standards?
- How cost-effective are our rehabilitation and preventive maintenance techniques?

The converse to all these questions and issues is also germane. What happens to the pavement condition and life of our networks when we lower our quality standards? Many states have performed this type of analysis and have clearly documented that the cost of quality is justifiable when compared with the additional benefits. The tools of pavement management allow us to conduct these important types of engineering analyses.

FHWA's new pavement management policy and those for the other five ISTEA management systems were issued as a federal regulation in December 1993. All federal-aid roads—more than 900,000 centerline mi—must be included in PMSs. This increased coverage presents a significant challenge to all of us. When we developed our policy we made an important distinction between federal-aid highways on the NHS and those that are not on the NHS, because our emphasis is on the NHS. Our policy specifies a set of standards that PMSs must meet for the NHS. States can go beyond these standards, and we encourage them to do so. Our policy gives each state full flexibility on establishing pavement management standards for the roads that are not on the NHS.

In a nutshell, our standards for the NHS require a PMS to have an inventory, project history, traffic, load data, and condition survey. The PMS must also provide an investment analysis that produces a prioritized list of recommended projects with recommended preservation treatments for single-year and multi-year periods using life-cycle cost analysis. This provision, which I have quoted verbatim, is designed to ensure a cost-effective and justifiable pavement preservation program.

The standards for the NHS also require an engineering analysis of the design, construction, rehabilitation, materials, mix designs, and preventive maintenance of pavements related to their performance. We will use this analysis to ensure the best quality pavements we can buy for the money.

Let me share my views on where we are now and what the future holds. First, do we currently have all the resources in place to fully implement and use PMSs? From a federal and state perspective, staffing is in short supply. This is a significant hurdle and it's not going away anytime soon. We've all been faced with staffing cuts, personnel ceilings, and budget constraints. Yet we must somehow dedicate the staffing levels needed to get the job done. Fortunately, we have a number of qualified and experienced consultant firms to assist us, not to mention the resources in our universities.

Second, will we be able to put PMSs in place for all federal-aid highways by October 1997? It won't be easy because of the large number of miles and the many local agencies we must cover. My crystal ball tells me that some federal-aid highways may not be covered. Will we then impose sanctions? We will look at each case individually and make the appropriate determination at that time. If an agency lacks the resolution to implement the PMS provisions in ISTEA, FHWA will consider sanctions.

Third, do we currently have all the technology in place to collect the desired engineering information and analyze PMS data? We have made great progress in the last two decades but we need to go further. We need to use new technologies when appropriate, such as ground-penetrating radar that can measure pavement layer thickness at highway speeds in a nondestructive manner. We need rolling deflectometers to measure structural carrying capacity at the network level. We need to advance fully automated condition survey equipment. Finally, we need to collect and report our PMS data in a more uniform manner. These are just some of the major technical areas in which we need to work in the future.

The fourth question is, will we use PMSs in the future to help us manage our vast network of pavements so that we can compete in the global economy by moving people and goods cost-effectively? The answer is absolutely yes, because we are dead serious and fully committed.

The fifth and final question is, what does all this mean? Pavements are what people drive on and judge us by. Automobile drivers want a smooth, safe road to get them to and from work. They want minimal disruptions when we rehabilitate the road, and truckers want to drive from Point A to Point B with their kidneys and cargo intact. We must remember for whom we work and what we are supposed to provide. People, be they motorists or truckers, expect good safe pavements. The taxpayers want their tax dollars used in the most cost-effective way. Used as intended, our PMSs will satisfy the expectations of the automobile driver, truck driver, and taxpayer. We owe it to motorists to provide the best road we can for the money we have. This means that we must carefully conduct engineering and investment analyses to make sure we invest productively. We must concentrate on using PMSs to fix the right road, at the right time, with the right preservation treatment, at the right cost. We owe this to ourselves and we are accountable to our employer, the taxpayers who use American roads. Don't use a PMS because ISTEA mandates that you must. Do it because it's the right thing to do.

Welcome Address from the Texas Department of Transportation

William G. Burnett, *Texas Department of Transportation*

I'm here to represent the Texas Department of Transportation (TXDOT) and I'm glad I have the chance to welcome you to Texas and say a little about what we're doing to manage pavements. As some of you may know, we're trying to forge a path for ourselves in transportation that exceeds anything we've done before. But to attain such a lofty goal, we must first concentrate on what that path is made of and what tools will best help us follow it.

TXDOT has some great ideas about intermodalism, especially since the agency dropped the word "highways" from its name and became a department of transportation. But just because the word "highways" left the name does not mean it left our business. Regardless of what other modes of transportation we work with, we'll always come back to the mode that humans have been using for centuries: the road.

TXDOT has some 77,000 mi of pavement to worry about. Texans may have our airplanes and our boats and our bikes, but once you get on the land, our roads are "it." And many of our 77,000 mi are not only "it," they're old, most of them having been built in the 1950s and 1960s. Many of these pavements have now exceeded their original design life and have begun to show distress such as rutting, cracking, and rough ride. In fact, a fiscal year 1992 report showed that only 66 percent of Texas highways were in very good condition, and our overall ratings will continue to drop as these pavements outlive their design life.

In the 1970s we started trying to document the conditions of our roads in a pavement evaluation system. This system stopped at recording the data. In the late 1980s we decided to integrate the data into a pavement management system that could analyze the information, give us condition reports, project distress levels and a variety of rehabilitation strategies, and provide cost estimates and prioritization schemes.

Because of its massive nature, we divided the project into two segments. The first is a network-level segment that allows me, as an administrator, to look at the entire statewide network and make informed decisions about where funding should be allocated and into which programs it should go. The second segment will allow area engineers and maintenance supervisors to look at specific project-level analysis. These two segments together will allow TXDOT to make the best decisions about where pavement rehabilitation starts and what kind of rehabilitation is needed. We hope to have the first segment or network-level system operational by the end of the year, and the second level, the project-level system, up and running in the near future.

Some of our efforts in Texas are on the leading edge of pavement technology. Many of you have signed up for a field trip to Victoria after this conference. We are constructing a revolutionary piece of accelerated pavement testing equipment we refer to as the Mobile Load Simulator. Although this equipment is still in the development phase, I am told it is operational and will be demonstrated to you.

But our edge is not so great that it stops us from spending $1 billion each year on pavements. We've collected pavement information for 10 years, but it had rarely before been used in pavement design. We hope to make it more accessible and to use it to closely observe how specific designs, materials, and construction techniques perform over time. All this information will give us a much more accurate estimate of our future needs. We have long needed this type of reliable procedure to select pavement type and perform a life-cycle cost analysis to better estimate our needs.

I could go on about what Texas is doing or planning for the future in the area of pavements, but I really came to hear what you are doing. Again, welcome to Texas, and if you have any problems while you are here, and specifically while you are at this conference, just grab one of our TXDOT staff. Thank you for this opportunity to make our pathway a smoother one.

Welcome Address from the Ontario Ministry of Transportation

Robert W. Oddson, *Ontario Ministry of Transportation*

On behalf of the province of Ontario I would like to add my voice to those of Dean Carlson and William Burnett in welcoming you to this conference. As a cosponsor of the conference, it is indeed a pleasure to note the wide interest in pavement and infrastructure management, both locally and internationally, and the importance placed by each of us and our agencies on this discipline in helping to maintain a cost-effective, efficient highway transportation system.

In these times of economic constraint the expenditure of public funds on transportation infrastructure must compete with ever-increasing community, social, and health demands. It is becoming more and more important for the agencies we work for to get the best return from their transportation investments. These returns can be and are increased significantly through the advancement of the art, science, and practice of managing pavements.

Past conferences, coordinated by Ontario and cosponsored by FHWA, had these broad investment objectives in mind. The first of these forums, which took place in 1985, attracted 250 participants from 12 countries, representing 75 federal, state, and local agencies. The second conference in 1987 attracted 330 executives, practitioners, and researchers from 33 countries. Our third international conference will see these numbers significantly surpassed, once again demonstrating the worldwide interest in exploring best practices, methodologies, and technologies in maintaining and managing pavement infrastructures.

Dr. Ramesh Kher, who coordinated and chaired Ontario's 1985 and 1987 conferences, established four basic thrusts to be integrated into all pavement management proceedings:

- Improving the broad understanding of pavements, pavement management issues, and problems by all practitioners at all organizational levels within all transportation jurisdictions;
- Developing pavement management solutions based on objective evaluations, along with comprehensive integration of all pavement maintenance and rehabilitation activities;
- Developing new technologies, methodologies, and materials where existing ones have demonstrated their failure to perform in a cost-effective manner; and

• Incorporating the idea of continuous improvement in all aspects of pavement management by bringing together broad segments of the industry in one major event.

On reflection these initiatives served both conferences well. The proceedings continue to benefit many transportation agencies and pavement practitioners around the world. Similar objectives have been established for this conference, and I am confident that the papers presented and debated during the next several days will have equal importance in our repository of pavement management information.

Dr. Kher, although unable to be with us today, would indeed be pleased to note that the principles sponsored and promoted during these earlier conferences continue to be important in setting the agenda for this year's conference. The importance of a forum such as this cannot be overestimated in advancing ideas, solutions, and understanding in fields as complex as long-term pavement maintenance and management.

My congratulations and thanks to those responsible for the development, organization, and promotion of this conference:

• TRB for coordinating the conference, including printing and distributing the proceedings;
• FHWA for its cosponsorship;
• Dr. Ralph Haas for taking on the role of conference chair;
• The conference steering committee; and
• You, the participants, for your enthusiastic interest in and contributions to all facets of pavement management, which will ensure the success of this and future conferences.

So where do we go from here? Some 7 years have passed since we last convened to pursue all aspects of infrastructure management on an international scale, a period of time many of us feel is too long. To prevent this lengthy delay from recurring, the Ontario Ministry of Transportation proposes to include a strong technical module focused on pavements in the 13th International Road Federation Conference, hosted by Ontario in Toronto in 1997. Your support and participation in this event would be most welcome.

Keynote Address

Fred N. Finn, *Consulting Engineer*

In his opening remarks at the First International Conference on Managing Pavements, Dr. Ramesh Kher indicated that Canadian and U.S investment in road infrastructure is more than $1 trillion, which implies a tremendous worldwide investment. Clearly, such an investment requires a high degree of stewardship to continually provide adequate performance at a minimum of cost. It seems apparent that traditional, and highly subjective, decision making is inappropriate to the task.

A subtitle for each of the past conferences could have been "Pavement Management Systems Development and Implementation, Present and Future." My remarks will attempt to address the past, the present, and the future of pavement management systems (PMSs).

For me the past began in 1969 when I was working with Ron Hudson and Frank McCullough to relate basic material properties to pavement performance. With the help of Karl Pister at the University of California, we realized that considering material properties one at a time would be an exercise in futility. However, it was possible to develop a better understanding of how and why pavements perform as they do by considering material properties as part of a system representing the total pavement structure and by recognizing the interdependence of material properties and pavement response such as stress, strain, and deformation. The results of that effort, as part of the National Cooperative Highway Research Program (NCHRP), eventually led to a series of NCHRP reports dealing with the application of systems engineering to pavement design and structural analysis for the prediction of pavement performance. On the basis of this experience, in 1972 I presented a paper at the annual highway conference sponsored by the University of California in which I outlined the possibilities of a PMS as a realistic tool to help managers and engineers determine the best time and type of rehabilitation for site-specific projects. By 1974 Dr. Kulkarni and I, along with Messrs. LeClerc and Nelson of the Washington Department of Transportation (WASHDOT), had developed a first iteration of a project-level PMS. The WASHDOT staff of Nelson and Jackson, along with Dr. Mahoney from the University of Washington, expanded and improved on the original version with the result that a usable and relevant system has evolved for Washington. By 1975 it was realized, through conversations with management-level staff in the Arizona Department of Transportation, that a management system was needed to address the entire road network simultaneously. It was suggested that the network management system should be capable of achieving both short- and long-term objectives. In the short term, the system should generate a list of projects that required specific types of rehabilitation in order to meet performance objectives within a constrained budget. In the long term the system should provide reliable budget estimates for maintaining the network in an acceptable condition. In 1975 the technology was not available to address this aspect of the problem, however.

In the United States and Canada, people like Golabi, Kulkarni, Nazareth, Lytton, Haas, and others developed mathematical models to satisfy the constraints of performance and budget and, with the help of highly qualified programmers, developed network PMSs. These developments, although occurring at about the same time, often used alternative technologies to achieve similar objectives. These individual and independent efforts led to a variety of network PMS methodologies.

My purpose in mentioning this particular experience and one perspective of the evolution of PMSs is to make several points: (*a*) we have been working on the development of PMSs for at least 25 years; (*b*) we must recognize the difference between the project and network levels of PMS; and (*c*) the development of PMSs requires knowledge and experience in such areas as pavement engineering, operations research, programming, statistics, modeling, and economics and requires input from agency personnel familiar with the problems and needs of the agency. Also important is support, patience, and commitment from top management for all phases of development and implementation.

This look into the past is based on my personal experiences and primarily represents events in the United States and Canada. However, I suspect that similar activities were also taking place internationally at about the same time.

A review of the proceedings of the 1985 conference indicates that technologists and managers, not always the same group, were interested in the development of PMS at the project and network level. Dr. Thomas Larson, former Federal Highway Administrator, indicated then that "... there is a need for innovation. In order for engineers and managers to be good navigators, there should be a desire for change by skillful professionals who can make a difference in the way decisions are made and which will result in reduced costs and improved performance." He pointed out that "... without dollars there will be no need for pavement management and without good management there will not be enough dollars to go around." Further, he noted that unless we can have a stream of innovations that will produce equal or even better services to the public using our generally shrinking buying power, we will cease to be competitive and our profession will suffer. More important, society will suffer, so our challenge is very clear. These comments from Dr. Larson are as applicable today as they were in 1985.

Subjects covered by papers at the 1985 conference included (*a*) educating the public and highway officials about the merits of PMS, (*b*) project and network PMS, (*c*) PMS support for funding and planning, (*d*) collection and use of information, (*e*) pavement performance and prediction models, (*f*) ranking and prioritization, (*g*) cost calculations, and (*h*) implementation.

With regard to implementation, one paper noted that there are four basic questions for a PMS relative to planning and programming maintenance and rehabilitation of pavements:

1. Where should investment be made?
2. How should investment be made?
3. When should investment be made?
4. What are the results and feedback?

If an agency has a system that can answer the first three questions and can document results from the feedback, it has workable PMS.

Pitfalls to implementation noted in 1985 included (*a*) mismatch between PMS and agency resources, (*b*) mismatch between PMS and agency needs (i.e., what the agency really wants from the PMS), (*c*) overselling of PMS ease of development and results, and (*d*) inadequate attention to institutional issues.

My experience up to 1993 suggests that those pitfalls are still with us. But in addition I would add that there is built-in resistance or inability to change the traditional ways of doing business, and a certain amount of "black box" phobia by management, in approaching a computerized management system whose architecture and functions are not always transparent.

Papers presented at the 1987 conference tended to be related to examples or case histories of implementation as well as the development of technology. Major issues identified included a somewhat wider range of topics than in 1985:

1. Institutional issues;
2. Interface of project and network systems;
3. Use of automation for data acquisition and data requirements;
4. Prediction models, both deterministic and probabilistic;
5. Benefits of PMS;
6. Barriers to implementation;
7. PMS at local, state, provincial, and federal levels;
8. Definitions or descriptions of performance;
9. Ranking and optimization;
10. Expert systems; and
11. Truck size and weight.

In 1987 reports of implementation were presented by representatives of 15 countries. As would be expected there was considerable duplication of subjects among papers and discussions at the two conferences. The main difference in 1987 was in the emphasis on implementation and the recognition of institutional issues as a major factor in successful understanding and use of the PMS. Alternatives were provided relative to such factors as ranking, prioritization, optimization, performance, and the perception of project and network management systems. It was also clear that there were almost as many methods for achieving PMS as there were agencies developing PMS—a diversity that resulted from different objectives, resources, and technological capabilities, and that has led to some confusion.

A review of the program for the 1994 conference indicates that representatives from some 25 countries will present papers or participate in discussions related to such topics as the following:

- Appropriate systems: development or enhancement of systems appropriate to the agency;
- Implementation issues: innovative ways to market PMS to decision makers;
- Institutional issues: ways to overcome institutional hurdles to implementation caused by the internal organization of an agency and by lines of communication and locations of power within the agency;
- Managing information: how to measure, store, and retrieve information;
- Analytical issues: development of prediction models, optimization, and user costs; and
- New frontiers: emerging issues likely to affect pavement management.

About half the sessions and topics are concerned with management issues related to setting clear objectives as well as the commitment to implementation, and half are concerned with technical issues. Two topics of utmost importance will be introduced and discussed this morning as part of the opening plenary session. John J. Henry and William D. O. Paterson will discuss "What Price Harmonization and What Benefits from Standardization?" W. Ronald Hudson and Ralph Haas will speak about "Costs and Benefits of Pavement Management."

In the middle and late 1970s, a number of states in the United States saw the benefits of having a PMS and initiated independent studies related to its development. These efforts led to the development of a variety of systems designed to meet the individual needs and resources of the state agency. These independent actions have led to some confusion as well as some benefits.

The benefits at the state level are the development and implementation of PMSs that have provided much-needed information concerning the inventory of pavements, their condition, estimates of budget requirements, maintenance recommendations for specific projects, and such benefits as will be enumerated by Professors Hudson and Haas. The development by states has also provided, in some cases, spin-off to local agencies.

The confusion, resulting from independent developments, stems from the fact that various state and local agencies perceive the requirements and benefits of PMSs differently. Differences of opinion relative to performance requirements, the use of various technologies, approaches to the project and network requirements, criteria for establishing priorities, ranking and optimization, the need for deterministic or probabilistic prediction models, and the pros and cons of including user costs as part of the cost analysis are examples of some of the sources of this confusion. I hope those issues can be discussed during this conference, with possible recommendations than could help resolve the question of standardization.

Definition of Performance

We commonly refer to functional performance and structural performance of pavements. Functional performance usually refers to ride quality or comfort as measured by smoothness or roughness. However, how are the two related? At the present time there is objectivity only on the side of measuring roughness. Even here we have not determined the best measurement and summary statistic for that unique characteristic of roughness, or surface profile, that relates to comfort as experienced in the wide range of vehicles operating on our highways.

Structural performance can refer to physical distress in the pavement surface or to the ability of the pavement structure to resist the occurrence of distress. The ability to predict when distress will occur, before it is actually visible, is considered useful in order to maximize the benefits of preventive or preemptive maintenance or early rehabilitation. The principal way to make such predictions, at the present time, is by establishing relationships between deflection or curvature and the occurrence of distress. Such predictions are not considered sufficiently reliable to use as the basis for programming funds for preemptive maintenance or rehabilitation. Efforts to use surface deflection or curvature, in my opinion, are not likely to be productive as reliable predictors of distress. Development of improved mechanistic-empirical models with the ability to simulate a variety of material properties, seasonal effects, aging, and traffic combinations will have a better chance of success.

Safety can also be considered as an attribute for PMSs. However, because safety has unique ramifications, it is often evaluated outside of the prioritization or optimization aspects of a PMS and must be dealt with largely on the basis of policy. However, as suggested by Mr. Carlson in his opening remarks, economic considerations regarding safety should be evaluated objectively to realistically program funds to achieve a safe highway facility.

Definition and Evaluation of Pavement Distresses

The evaluation of distress in any standard format is still a matter of opinion as to what types, extent, and severity are critical and essential for use in a PMS. In the United States the Strategic Highway Research Program (SHRP) staff has issued a "Distress Identification Manual for the Long-Term Pavement Performance Project." This manual is to be used by contractors assigned to evaluate in-service projects included in the long-term performance phase of SHRP. Fifteen types of distress are identified for pavements with asphalt concrete surfaces, 16 for jointed portland cement concrete, and 15 for continuously reinforced concrete surfaces. This manual was developed primarily for research; however, it could be useful at the project level of PMS. The manual illustrates the kind of information needed to help standardize data acquisition. Every agency needs such a manual for use with the project and network PMS. It would be useful if one set of manuals could be used nationwide. Each agency could select, from the list of distresses in the manual, the type of distress or distresses most likely to occur and most significant to the project and the network. Agencies in other countries have also developed comprehensive manuals used to identify distress.

Techniques for the Development of Prediction Models

Some PMSs do not include prediction models at the network level, and some don't even include them at the project level. The absence of prediction models is usually due to a lack of confidence in their ability to predict performance. The inclusion of prediction models should be a must for a fully implemented PMS. As information is developed from research, improved models can be developed, and some objections to them can be mitigated. Hopefully, mechanistic models can be developed for pavements at the project level. Statistical models will likely remain the basis for network-level predictions.

Costs and Their Computation

There is confusion regarding which costs to include and how to determine them. What constitute initial costs are relatively clear; however, reliable estimates of initial costs at the project level, and especially at the network level, must be recognized as having a degree of uncertainty. This uncertainty must be carefully evaluated when cost differences between alternative actions are relatively small.

The method used to determine salvage value is also the subject of some controversy and confusion. The two most common methods rely on estimating the worth of the in-place materials if they are to be reused or the remaining life associated with the last maintenance or rehabilitation action.

Any relationship between the cost of routine maintenance and pavement condition has proven to be elusive.

Differences resulting from errors in estimating salvage value or routine maintenance cost during the life of a project may not be overly critical, since relatively small present-worth factors are applied to routine maintenance and the offsetting effects of salvage value. However, such factors may be important when alternative considerations have narrow cost differences, and they should be included in cost estimates.

There exists major confusion, or a difference of opinion, with regard to user costs. One argument suggests that such costs are not reliably known for pavements maintained at a relatively high level of functional performance. Some countries, under the leadership of the World Bank, have developed what they consider to be reliable user cost information. However, many PMS developers believe that this information may not be applicable beyond the limits of the investigation. Some investigators in the United States argue that ride quality is a suitable surrogate for user costs, at least until reliable information is developed for application in this country. Possibly these same arguments are ongoing internationally as well. It seems clear to me that total costs, including user costs, would be the ideal objective function for a PMS when attempting to determine optimal M & R strategies based on the lowest costs. Questions that should be answered include how user costs are related to levels of distress or roughness and how to estimate the cost of delays incurred by the user as a result of various M & R actions.

Marketing PMS

What techniques can be used to convince staff at all levels of the benefits and importance of enthusiastic support for a proposed PMS? Support is needed across organizational boundaries within most highway or transportation departments. There is a natural aversion to change. But if benefits for each group can be identified, support should be possible. How to obtain this support can be a critical issue to real implementation.

Pros and Cons of Standardization

At the national level standardization has a number of advantages: (*a*) the ability to summarize the past, present, and future condition of pavements across political and geographic boundaries; (*b*) the ability to report performance trends, both structural and functional; (*c*) the ability to combine resources for the research and development of technology for both project and network PMSs; and (*d*) the ability to establish national standards or goals for pavement performance. The disadvantages are essentially the opposite side of the coin: (*a*) difficulty in comparing the condition or performance of pavements at the national level, (*b*) difficulty in combining information and use of technology, and (*c*) inability of agencies to help each other solve common problems.

There are definite advantages to having separate systems at the state or local level. For example, the system can be tailored to the needs and resources of the agency without being required to meet national standards. There may be greater opportunity for innovations, which may not always be compatible with national standards or requirements. A degree of competitiveness could develop among agencies, which might lead to more innovations for PMS. Performance thresholds can more easily be adjusted to meet the needs of the local agency. The time required to develop a system will likely be less if only local needs are to be satisfied.

At the present time I sense no strong movement toward a single national pavement management system in the United States, although there appears to be some movement in this direction for bridge management. I believe there is interest in exploring the feasibility of a more standardized measurement and summary of pavement distresses and profiles. Current work by ASTM, AASHTO, TRB, and FHWA indicates a common interest in this activity. Some countries have essentially a single generic system, which has been adapted to local requirements. A challenge for this conference could be to make recommendations for standardizing performance and distress measurements so that the results, uniformly summarized, would have credibility for addressing needs and could be used to measure the health of the system over time.

I would like to offer a few comments about the future, especially as it can be affected by research. The first is that we should determine what research is most needed and will have the highest payoff in terms of return on investment and timeliness of delivery.

Drs. Hudson and Solminihac of the University of Texas have undertaken a project to identify research needs. Their investigation is based on responses from 308 PMS practitioners from 21 countries. The results of their study have been broken down into two categories: short-term opportunities for innovation and research and long-term opportunities. Three broad categories of need stand out in their report:

1. Development of automated data collection equipment and analysis methods for standardized pavement distresses and roughness measurements;
2. Improved life cycle or remaining life prediction methodology; and
3. Better understanding of costs, including the role of user costs.

Those responding expressed interest in (*a*) standardized PMS concepts, (*b*) integration of all infrastructure management systems, and (*c*) coordinated education and information efforts for all levels involved in management systems, from technologist to decision maker. As Dr. Larson said in 1985, PMS needs a stream of innovative developments, and I would add that research is the headwaters of that stream.

In closing I would like to note that PMS offers the most effective concept to maximize the benefits in planning and programming pavement maintenance or rehabilitation. However, in dealing with our peers, with management, and with the public, we need to keep in mind that Moses did not include PMS as an eleventh commandment and that we have not yet achieved perfection in its development or administration. Our mission this week will be to share with one another and to work toward reliable and credible PMSs.

Some of the limitations of PMS are as follows, from my perspective:

1. Until automated equipment is available for measuring distress, it is normal to evaluate a section or segment by sampling only a portion of the section. How representative is the information? Are the data from the sample to be summarized and incorporated in the PMS as an average or as some distribution? In most cases, maintenance or rehabilitation is not triggered by some average condition. Information concerning pavement condition from a sample is our best estimate; however, we need to realize that there is some uncertainty about how well the sample represents the total section.
2. There is the question of the reliability of prediction models and how well such factors as weather, aging, traffic, subgrade material properties, and drainage are included in them. How sensitive are the results to these factors?
3. There is uncertainty about the methods used to obtain cost estimates. How reliable are the cost data, particularly at the network level? Have we given adequate consideration to user cost, either directly or by use of surrogate considerations?
4. How credible are the performance criteria? At the present time most criteria are set by members of the agency with only minimal input from the actual users, particularly the truckers who operate 18-wheelers.
5. How credible are the recommendations generated by the PMS? Recognizing that there is the possibility of some risk in setting priorities or M&R policies for optimization, provision should be made for the use of judgment in applying the results.

The results or recommendations provided by a PMS are highly dependent on the applicability and quality of information in the data base and on any assumptions made in the development of the prediction and economic models as well as the performance criteria used to identify when maintenance or rehabilitation is needed.

I do not want to end my remarks on what may sound like a negative tone. The value of pavement management systems is apparent by your attendance and participation in this conference, and by participation in the previous two conferences. It should be made clear to engineers and managers that PMS is an essential planning and engineering tool for maximizing benefits and minimizing costs to users. We need to keep moving forward with innovations to enhance future PMSs and to better use the systems that have already been developed and implemented.

Standardization or Harmonization: What Is Needed for Pavement Management?

John J. Henry, *Pennsylvania Transportation Institute*
William D. O. Paterson, *World Bank*

"Standardization" is welcomed by those who view it as the way to a well-ordered, structured existence and resisted by those who regard it as an imposition with the possibility of unfamiliar methods, extra effort, and costs, perhaps without identifiable benefit. How desirable is standardization, and in particular, what are the needs for standardization in pavement management?

In pavement management, a wide variety of technical activities being propelled into regular use were, until the last decade, only in the research and development phase, or were restricted to special applications. Specific information-gathering tasks—such as measuring pavement deflection, skid resistance, roughness, and traffic loadings—have become requirements for regular monitoring of road conditions and demands. Management systems providing a basis and support for decision making are themselves different products that can be selected to meet differing levels of need.

Only a few localized attempts were made to apply a systems approach to managing road pavements in the 1970s. Today, literally thousands of highway agencies and local authorities throughout the world are making decisions on what to measure, how to interpret data, and how to formulate the decisions that will lead to the optimal management of their road assets. In the 1970s the choices were largely dictated by the road agency of the jurisdiction, with the strong influence of national or regional research institutions. Now with the growing globalization of trade and information exchange, and with fierce pressures to economize, the choices can be made from beyond the immediate jurisdiction, if the administrative framework allows it. If a better way exists somewhere else, why not consider it?

Despite the variety of emerging approaches, there are common barriers to change. The pragmatic one is familiarity with the local approach and a preference for doing it "our own way." The other is the lack of a means to compare across options and so relate new data to previous data. In such situations a set of standards becomes valuable, either as a norm to be followed directly or as a norm by which commercial alternatives can be compared and their implementation controlled.

How should standards be used to support and benefit pavement management? This raises the question of whether the differing approaches at local, national, and international levels should be reconciled by seeking common standards or harmonizing differing standards. The choice can be characterized simply by this question: do we seek to achieve uniformity in all respects or in the end result (Figure 1)? The latter certainly would provide the flexibility and diversity needed in the global market.

STANDARDIZATION

The purpose of a standard is to provide a common basis for performing a particular task or meeting a particular objective, so that when followed by different people, in different places, or at different times, equivalent or comparable results can be obtained. The common use of standards is to gain compliance in producing materials, products, or information. They may be used as specific citations in the technical specifications of contract documents to avoid the necessity of reproducing tedious detail for regular use. They may be used as a schema of best practice. Standards are used to support quality assurance schemes, as a basis for quality control, and as a means for ensuring the reproducibility of results. They cover materials, products, systems, services, procedures, terminology, and concepts.

To meet this variety of purposes there are different types of standards, such as the following:

- Methods or procedures, specifying detailed steps to be followed for a test or activity;
- Specifications of the attributes or properties of items such as materials, equipment, or information; and
- Guides indicating good or preferred practice and standard concepts.

Many standards are rules that derive their credibility from the establishing authority. They are only applicable when invoked. For wide credibility and applicability, therefore, the knowledge base and the development of consensus among clients, users, and industry are crucial.

Technical standards tend to evolve through five typical developmental stages:

1. Innovation or initiation of a test or method, by an implementing agency or through research and development;
2. Test-specific specification prepared by or for an implementing agency;
3. National standard for specific test method and device;
4. National standard for test method (applying to various devices); and

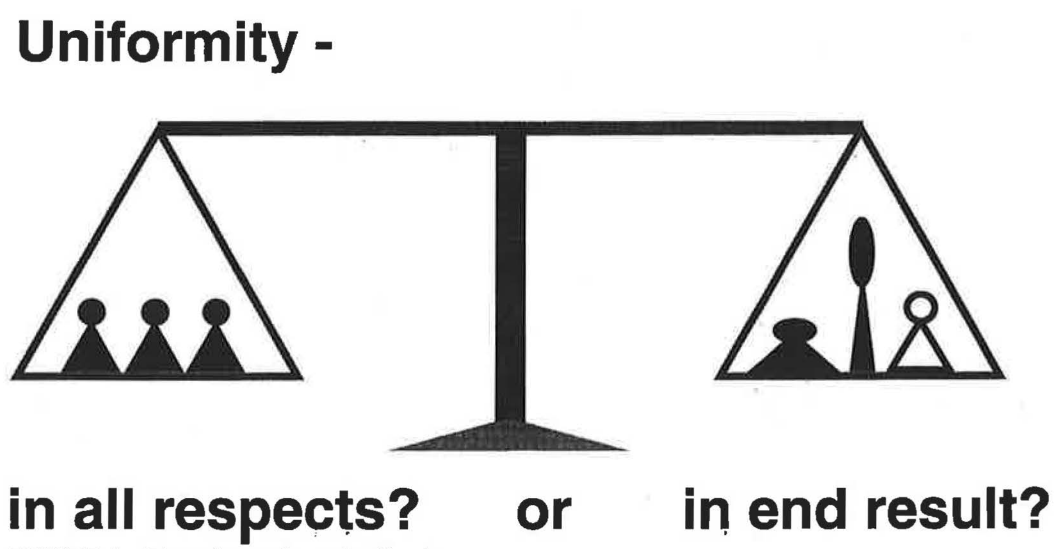


FIGURE 1 Two views of standardization.

5. Harmonization in generic standard of test for all methods and devices (national or international).

Most highway engineering standards have first been developed by an implementing agency as a method of best practice to achieve uniform results from a repetitious task. In the first stage, particularly for new techniques and concepts, the standard develops around a particular method or item of equipment that is an invention or the product of research. The second stage is to codify the essence in writing, for use as a specification of a method or system by an implementing agency. Thus, before and during the evolution of the concept of pavement management, we have seen the issuance of standards on, for example, the Benkelman beam deflection equipment and method, a specific manufacturer's locked-wheel brake-force trailer, a specific commercial road profile measuring device, and so forth. Written by a public agency, research institution, or manufacturer, these early agency-specific standards served a useful purpose by allowing these techniques to be introduced and used by others beside the inventors.

The third stage is the preparation of a national standard for a specific method or device to meet the needs of multiple users and agencies. This distinguishes a standard from regular specifications, methods and guides that are otherwise applicable only in their locality and are typically subject to local variations. Procedures are reviewed, agreed, and formalized. The experience of all users of a particular device or method is pooled. The standardizing of procedures and equipment improves reliability, repeatability, and reproducibility.

However, as the industries grow and variants are developed for each device or method, the number of standards would have to proliferate if all competitors were to have equal access to the market. If a client (e.g., a road agency) adheres too rigidly to a particular technology, specifying one device, innovation and improvements may be suppressed. Such restrictive practices may result in technical or economic inefficiency. Whereas restrictive specifications can satisfy an immediate need, in the long run liberalization will be needed to ensure that the best practices will be achieved. Standards have had to evolve toward a focus on the end-product, be it a data item or a product, specifying procedures or equipment only where they have a direct bearing on the end product. Stage 4 is thus the development of a generic standard covering all variants within a device or method group. Examples include response-type road roughness meters and locked-wheel skid testers.

The challenge in developing Stage 4-type standards has been to identify the essence of a method and distinguish for example when it is unnecessary to require adherence to the mechanical design details of the testing equipment (a factor that may favor one manufacturer's patented rights to the exclusion of others') and which elements of the test are fundamental to the property being measured. Thus, for example, the measurement of road roughness evolved from a standard instrument, the Bureau of Public Roads roughometer, to a cluster of standards for various individual devices, to general standards on response-type equipment and on other clusters of methods dealing with quite different principles of measurement of road surface profile.

Harmonization

When the market has produced different methods or equipment for measuring a pavement or traffic attribute, the issue that then arises is how these can be compared and the best choices made. And if different agencies make different choices, which is inevitable in an active market, how can the end products be compared when necessary?

Harmonization is the process of creating a new reference standard to which existing standards can be related, whether they are maintained in parallel to the new standard or are subsequently replaced. It is Stage 5 of standard development.

Harmonization can be considered the gentle road to achieving standardization. In the context of a diverse market, it allows entry for a variety of players but retains a commonality of output. It is a means for allowing an agency to obtain the benefits of relating to a broader range of options. Without requiring abandonment of the existing method immediately, it permits either a planned transition to other options or the adoption of a universal standard.

We can identify at least four motivations for harmonization:

- Continuity—when moving from an old to a new measurement technology, to preserve acceptance test requirements, or to maintain consistency with historical records that are a rich source of empirical experience;
- Equity—when a national or regional agency allocates budget to regional or local jurisdictions, to provide commonly based measures of conditions and needs for comparison and assessment;
- Efficiency—the expansion of market opportunities allows entry of more suppliers, more competitive pricing, and more incentives for technological improvement; and
- Effectiveness—to accelerate the progress of knowledge on complex mechanisms involving numerous variables, such as those involved in road friction, by the exchange and pooling of findings and the resultant synergy that allows progress beyond the resources of any one group.

The goal of harmonization is founded on the notion that to make progress, whether technologically, efficiently, or effectively, it is useful to reduce the number of compliance requirements to the minimum essential and to eliminate conflicting requirements that might be applicable from different agencies. The strategy for success in harmonization is to identify the fundamental objective and characteristics needed to define the product or process. It recognizes that different paths may lead to the same goal. Performance-based specifications, for example, inherently imply that the ultimate performance is what needs to be assured, and the actual means (equipment, recipe, etc.) to attaining it are not relevant.

Lessons can be drawn from other sectors. The promulgation of de facto common or dominant practice does not necessarily bring the best solution, and may only formalize an inefficiency. Examples include the dominance of VHS over the more efficient Beta technology in the videocassette market, of DOS-based software over the icon-graphic interactive software until recently in the computer market, and the persistence of imperial measures in the dominant U.S. economy over the metric measures applying elsewhere in the world.

In pavement management, we must endeavor to move as quickly as possible from the initial, product- or process-specific standards applying to existing and new methods, to standards applying to generic clusters of methods, and wherever possible, to a reference standard that allows harmonization among those generic clusters. Where possible, we should avoid merely standardizing what is currently common practice and focus on identifying and achieving standards based on fundamental principles and best practice.

There are three approaches to achieving harmonization: correlation, calibration to an independent fundamental reference, and classification.

Correlation

A simple approach, and usually the first to be attempted, is to correlate the results of two or more methods and determine the relationships between their results, as shown in Figure 2. The approach is satisfactory when the methods are operating on similar principles, but experience shows that the correlation and the accuracy of estimating one result from the result of another method degrades considerably and is usually only fair when they operate on different principles or are measuring different aspects of the phenomenon.

Adjustment to Fundamental Reference

A stronger approach is to identify a fundamental characteristic that is relevant to the eventual practical use of the result of the test or method. The output of each method is processed

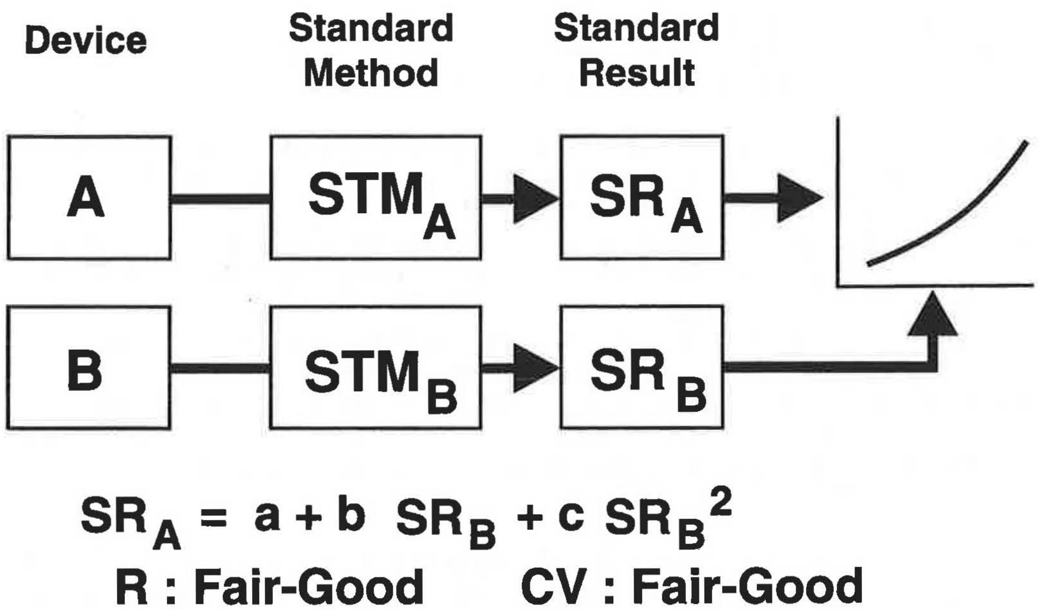


FIGURE 2 Correlation approach to harmonization.

to produce the fundamental characteristic, which then becomes the new measure to be produced by each method, as shown in Figure 3. Usually a major international experiment is needed to identify the reference, to establish its relevance and suitability to all methods, and to determine the correlations of the various methods to the reference and to each other. In the example in Figure 3, the outputs of Methods A and B are each processed differently from their usual results and the final result is expressed in the international units of the fundamental reference. Their standard results, SR_A and SR_B, are also produced and could be used in parallel or alternatively to the international standard. The output of Method C, which perhaps measures only the fundamental characteristic, is processed directly into the international units of the fundamental standard.

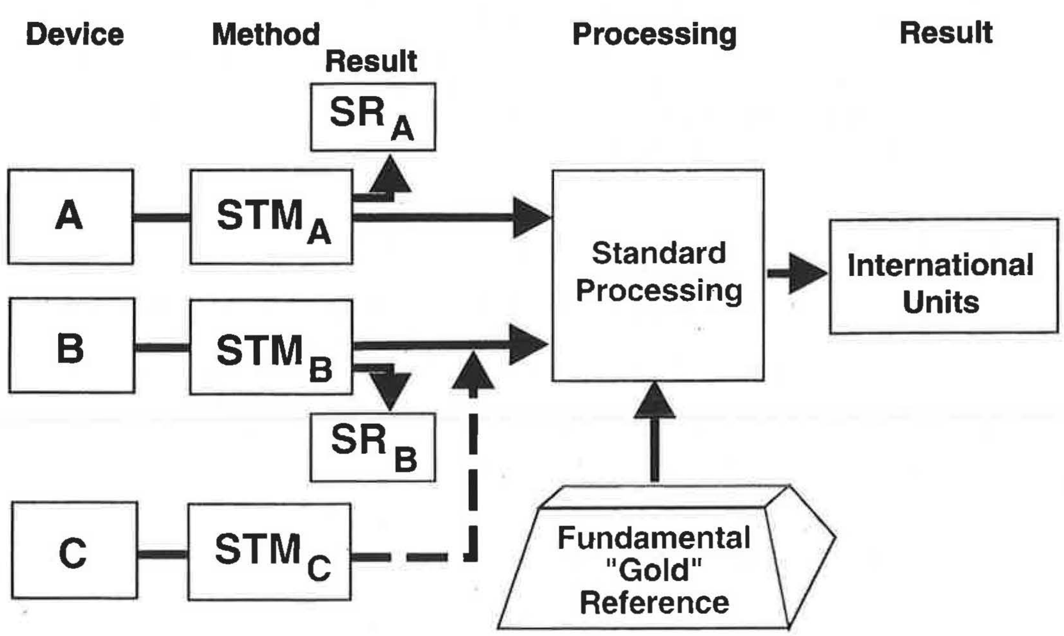


FIGURE 3 Harmonization by relation to fundamental reference.

Classification

Standardized classifications are emerging as one of the most versatile and useful ways of harmonizing aspects that are complex or do not have standard measures, such as survey methods, equipment capabilities, and terminology. By defining the characteristics of a class of devices or methods, both users and suppliers are given a common reference to define and quantify the capabilities relevant to the measurement. Several devices or methods would qualify for each class, and as new technologies or new devices come into the market such classes provide an immediate identification of their capabilities and relevant applications. Thus standard classifications are very useful for contract specifications and for public procurement procedures, allowing flexibility in the preparation of contract bids and the entry of different suppliers under equivalent conditions.

STATUS IN PAVEMENT MANAGEMENT

From the perspective of standards development, we now review the status and progress of standardization in pavement management: first, the tangible, familiar elements of specific data and information such as pavement condition and traffic; and second, the more conceptual aspects such as terminology, management system principles, and implementation issues. A listing of ASTM standards (*1*) relating to pavement management is given in Table 1.

Roughness

Until the 1980s, measurements of road roughness were device-specific and the standards that existed were intended to ensure the similarity of replicate mechanical devices, implicitly assuming that they would then yield comparable results. Standardization took the form of a standard such as ASTM E1215 on a two-wheel trailer or a dedicated reference vehicle set aside to be used only for comparison and calibration, such as the British Bump Integrator trailer or Australian NAASRA meter. Little was known then of the magnitude of the variations between like devices or of the uniformity of a device's measurements over time. The ubiquitous inches/mile or counts/mile statistics of cumulative relative displacement between axle and vehicle became common in American and British work, but the comparison among diverse devices was unknown, especially with the profile-measuring devices emerging in the United States, France, and the United Kingdom. Relations to the rolling-beam devices (Profilographs) and static straight-edge measurements of profile tolerances, expressed in similar inch/mile or inch/foot units but different scale, were not established.

The International Road Roughness Experiment (IRRE) in 1982 (*2*) and the preceding American calibration study (*3*) were landmarks in this situation and set a pattern that has become a model for the harmonization of other road measurements. The two primary objectives of the IRRE were to establish the correlations between various methods and to identify an independent calibration reference standard. In a broad-ranging factorial of nine response-type, two dynamic profile, two static profile and panel ride rating methods on flexible and unpaved roads, the experiment succeeded. The International Roughness Index (IRI) was defined as a mathematical transform of the absolute elevation profile of a single-wheel track—the transform being a quarter-car simulation with a cumulative displacement per unit distance (slope) as output—and roughness measurement guidelines were issued (*4*). Subsequently an S-4 type standard for calibration was developed in ASTM, the E1448 (Table 1).

The findings of the experiment and subsequent lessons learned are instructive:

- Whereas the correlations between methods were generally positive, they were weakest between methods of different principles or operational conditions, revealing both nonlinearity and wide dispersion.

TABLE 1 ASTM Standards Relating to Pavement Management

ASTM DESIGNATION	TOPIC	STATUS	LEVEL
Roughness and Profile			
E1364	Static level		4
E950	Profilometer	Under revision	3 to 4
E1500	Mean square numerics	New	4
	Ride number from profile data	Preparation	3
E1448	Calibration of response-type road meters	Recent	4
E1170	Vehicle simulation for IRI	Under revision	4
E1082		Under revision	3
E1215		Under revision	3
E1274	Profilograph method		3
Friction and Texture			
E274	Locked wheel friction		4
E303	British pendulum tester		3
E445	Stopping distance		4
E501	Ribbed test tire		3
E503	Diagonal braking friction		4
E524	Smooth-treaded test tire		3
E670	MuMeter friction tester		3
E965	Volumetric ("sand") patch		4
E1136	Radial treaded test tire		3
E1337	Peak braking coefficient test		4
E1551	Test tire for fixed slip testers		3
	Fixed slip friction testing	In preparation	4
	Variable slip friction tests	In preparation	4

- When influential operating conditions such as speed were normalized, the correlations improved considerably.
- The most successful harmonization was achieved with a reference based on the underlying absolute profile being measured, defined in a mathematical form relevant to the impact being assessed (in this case, the excitation of road vehicles in motion).

Assessing the effectiveness of IRI as a harmonizing standard reveals the following:

- The use of IRI as either the measure or the reference for roughness measurements has become widespread in the world, with an increasing number of agencies adopting it for formal statistics, and it is becoming the norm for data presented in technical publications, which has greatly improved the transferability of research findings.
- The commitment and support of public and international authorities have been crucial to the recognition and adoption of the standard. The collaborative involvement of several countries (developed and developing) and international organizations (such as the World Bank and the United Nations) both enhanced the credibility and impartiality of the result and created a willingness to adopt the result. However, where the technical organization or the government agency has not relinquished its preexisting standard, the international standard has not been adopted. In the United States the federal requirement to report federal roughness data in IRI has ensured its use for federal purposes, but not all states have replaced their systems.
- The role of private industry, particularly the manufacturers of road monitoring equipment, was pivotal because the provision of facility for reporting the IRI units of roughness in all recently produced equipment has encouraged users to use and become familiar with the scale and the standard. The built-in computation of IRI by road profile devices has also improved the reliability of the measurements.

• Concerns about IRI raised by some users have tended to focus on the definition of the processing algorithm, the quarter-car index, in two respects. First is the application of IRI to two-wheeltracks (some prefer the half-car index—which suppresses some roll effects like the old response-meter methods—to the standard's average path IRI, which is conceptually closest to the energy input into a vehicle). Second is its correlation with subjective ride quality rating, which although it is high, is diminished for rigid pavements because of a sampling average effect. Both concerns reflect differences over what objective function the "golden reference" should represent, some holding to past constraints and others reflecting newer objective measures. They can be resolved by clarifying the application guidelines first on the two-path measure and second on the segment length being reported.

Transverse Profile

The standardization of transverse profile measurements is still largely at Stage 3 of the process, with test-specific methods being applied for straight-edge rut-depth measurement and other agency-specific methods being applied for various automated devices. The process is moving into Stage 4 with the preparation of two ASTM standards, one on the straight-edge method and one on the transverse profile measuring capability of automated devices.

The challenge for harmonizing these measurements lies, as for roughness, in identifying the objective function. There are several definitions of the reference profile from which rut depth or other profile deviations would be measured. The two most common are straight-edge, which bridges high points across a wheelpath and is sensitive to the contact length; and the stretched wire, which envelopes high points across the whole profile. The harmonized standard must deal with a variety of profile deficiencies, including protuberances such as heave and ill-defined or irregularly placed ruts, longitudinal variations such as depressions, and crossfall, in order to satisfy the needs of users as an international standard. Consensus is needed on the objective—for example, identifying the depth of entrapped surface water, volume of surface profile correction, or impact on wheel tracking—before a relevant definition can be identified.

Pavement Distress

Pavement surface distress measurements have evolved on a very agency- or method-specific basis so there are many different systems, mostly at Stage 2 of the process. Progress to Stage 3 has been made for one method-specific measure in the recent publication of a standard for the measurement of pavement condition index (PCI) for airfields in ASTM Standard D5340 and the current preparation of one for roads. Likewise, the agency-specific standard for the Strategic Highway Research Program distress classification is under preparation as a national standard.

However, these relate to only two approaches: a combined index of distress modes and a research-level detailed method of distress recording. The latter provides multifactor descriptions of cracking, potholing, and other distress types. What of other approaches? There appears to be a need for an intermediate set of standard measures, quantifying each type of distress separately since these are often used to distinguish among different potential maintenance options.

New thinking may be needed for this area. The advent of automated condition monitoring, with the ability for automated image interpretation and digital image analysis, means that the methods of quantifying distresses need to be reexamined. A proposal for a universal cracking indicator (*5*) suited to both automated and manual methods suggests one promising approach to identifying a harmonized standard. The tolerances for precision and bias also need practical review; research-level precision on some aspects of distress measurement may be wasteful when the use of that information is only of a very aggregate and coarse nature, with ill-determined impacts on design decisions. A classification hierarchy interrelating increasingly detailed levels of distress characterization (6) is another possibility.

ASTM Committee E17 is following several approaches. In addition to method-specific standards, there are task groups considering distress definitions, a classification of distress measures of differing levels of detail, and a classification of automated survey equipment capability. But there remains much scope for finding and forging a basis for more universal harmonization.

Condition Monitoring Devices

The approach being followed in ASTM for multifunction automated condition monitoring devices is a variant of the classification approach that defines four dimensions of operation and various capability levels within each of those. Thus the class of a device is described by a four-character alphanumeric code covering all four dimensions: the measured attribute (longitudinal profile, transverse profile, crack width), measurement precision (six levels), transverse sampling intervals (three to six levels), and longitudinal sampling intervals (four to six levels), as summarized in Table 2.

Pavement Structure

Method-specific standards have been developed for common tests such as the Benkelman beam test and short-pulse ground-penetrating radar (e.g., ASTM D4748). Progress has been made toward Stage 4 generic standards, such as the general guide to deflection testing (ASTM D4695) and standard test method for falling weight deflectometers (FWD, as standardized in ASTM D4694). The Benkelman beam deflection has been acting de facto as a universal harmonized standard measure for many years, and it is time to consider whether another parameter is more relevant and appropriate for today's focus on FWD testing and mechanistic analysis. Alternatively it must be determined how the de facto standard would be standardized for the growing number of instances when means other than Benkelman beam are used to measure deflection.

The classification of deflection survey sampling levels in ASTM D4695 applies to all methods of deflection test and is therefore a Stage 5 harmonization. Deflection surveys are classified into three types indicating the typical sampling levels suited to strategic network evaluation, to project-level design, and to detailed studies, as indicated in Table 2.

Traffic Measurements

Most traffic measurements have been conducted to the specifications of an implementing agency, and in many instances these have been conformed to national (e.g., AASHTO) or federal specifications because of a national interest in traffic volume and travel counts as measures of economic activity. This was feasible given a relatively limited supply market of largely electromechanical systems.

Now the supply market has diversified with electronic systems capable of many functions previously impossible or performed manually. In response, the ASTM E17 Committee has developed a number of Stage 4 type standards to standardize best practices and to classify equipment capabilities, as noted in Table 1. These include a standard practice on traffic monitoring (E1442), vehicle classification based on axle detection (E1572) and a specification and classification of weigh-in-motion (WIM) systems (E1318). Under preparation are generic device standards for traffic monitoring devices and for tube counters.

The WIM standard is an example of the classification approach to harmonization. The classification defines four types of device capability and specifies the capabilities in each case, as shown in Table 2. Types I and II are suited to traffic load monitoring under either high or

TABLE 2 Examples of Classification Approach to Harmonization

CLASS	DESCRIPTION	EXAMPLES OF USE
Weigh-in-Motion (WIM) ASTM E1318-9		
Type I	Full data output (listed in E1318). Slow and high-speed use. Multilane use	Monitoring of full loading spectrum without interruption of traffic
Type II	As for Type I, but wheel load data not output	Monitoring of full axle-loading spectrum without interruption of traffic
Type III	Limited output. Medium speeds	Screening detection of load violations
Type IV	Limited output. Nil to creep speeds	Axle and wheel load enforcement.
Deflection Survey Sampling: ASTM D4695-9		
Type I		Strategic overview of network strength
Type II		Project-level design
Type III		Detailed and research studies
Automated Condition Survey Equipment (in process)		
X-p-t-l	X = functional capability; L = longitudinal profile; T = transverse profile; C = crack detection. p = measurement precision (6 levels) t = transverse sampling interval (3–6 levels) l = longitudinal sampling interval (4–6 levels)	

slow speeds, Type III to load enforcement screening, and Type IV to legal enforcement purposes.

Friction

Most measures of friction have been standardized around individual devices, and the many standards reflect the variety of test methods and factors involved—such as locked-wheel, slip, sideforce friction, diagonal braking, pendulum, laboratory tests for friction and polishing—and the equipment that conducts these tests, including the test tires.

Largely because of support from FHWA, the pavement friction measurement in the United States was standardized around the locked-wheel method, and calibration centers were established to ensure that the data collected were consistent across state boundaries. This example of a regional standard for pavement friction has also been applied in other countries such as Taiwan, Greece, and Kuwait. Other, inequivalent methods are in use around the world, including sideforce friction and slip friction measurement.

Harmonizing data from these three basic types of measurement is not straightforward since they measure very different characteristics. In addition there are many different systems in use to measure the sideforce, locked-wheel, and slip modes, and variations in equipment configuration result in different indices specific to the device used. The efforts in the United States to standardize the use of the locked-wheel method at least eliminated the potential for 50 variations on that method among individual states. Further complicating the harmonization of friction measurements is the lack of a "true" value against which to calibrate systems. Thus it is necessary to harmonize friction data information in addition to developing a single friction measurement.

The International Experiment to Compare and Harmonize Pavement Friction and Texture Measurements (7) was initiated by the Permanent International Association of Road Congresses (PIARC) to harmonize friction measurements in use around the world. The experiment was hosted by Belgium and Spain in fall 1992 and considered 51 friction and texture methods. There were 28 sites in Belgium and 30 sites in Spain, of which 40 were on roads, 14 were on airports, and 4 were at a race track. All measurements at a site were completed in as short a period of time as possible to avoid large temperature differences or other changes that may occur during a day. Each friction tester was operated at or close to three speeds—30, 60, and 90 km/hr—and each tester made two repeated runs at each speed. Macrotexture and British pendulum tester measurements were also made before the friction measurements. Thirty-seven types of friction measurement and 14 types of texture measurement were made at all sites.

It was found that harmonization of the friction data is possible, but only when the friction measurement is supplemented by a texture measurement. The friction and texture measurements are converted to two parameters, and these further describe an index defined as the International Friction Index (IFI). All texture measurements were used with the friction measurement of each device and, although some provided a better harmonization, most produced acceptable results.

It had long been recognized that a single friction measurement is not sufficient to evaluate the pavement for safety (*8*). In fact many authorities in Europe have taken both a friction measurement and a texture measurement simultaneously. In the United Kingdom there is a requirement to meet a minimum macrotexture depth in addition to a minimum acceptable sideforce coefficient. The proposed IFI with the two parameters that constitute it has the potential to advance the quality of the friction data used in managing pavements. In this example, the process of harmonization has increased the level of knowledge and offers significant improvements to the utility of friction data in managing pavements.

Pavement Management Systems

General aspects such as terminology, information management, and implementation of systems are also being addressed in standards. Terminology is often aligned by country of origin, as for example in ASTM E867, but some attempts are being made to relate and harmonize terms among languages through PIARC committees. ASTM standard guides under preparation deal with data priorities and implementation of pavement management in an organization.

For the whole field of road management information and methods, a generic classification approach has been devised by the World Bank (*6*), identifying four or more levels of information quality by the amount of detail, from the most detailed to the most summary types of information. The scope for using this generic framework for international harmonization is promising and is being applied in the consideration of new standards.

International Cooperation in Developing Standards

A close working relationship is being maintained between ASTM and other standards-developing organizations. Although the processes by which the various international standards are developed differ, good cooperation is being attained in several areas. The European group Comite Europeen de Normalisation (CEN) TC 220, SC 5 has working groups that are adapting ASTM standards for the measurement of texture depth by the volumetric technique (ASTM E865) and the British pendulum tester (ASTM E303). Although some word variations and clarifying statements are anticipated, the new CEN standards and the existing ASTM standards are expected to agree in practice. ASTM will consider any changes in the CEN documents to determine whether ASTM standards would be improved by adopting those standards.

An ASTM standard (E1165) has been incorporated in a standard proposed by ISO TC 22 SC 9 WG 3 for evaluating friction at test tracks used to evaluate tire performance and vehicle handling. In addition, experience gained in the development of the calibration centers in the United States led to the abandonment of attempts to develop a standard specification for constructing test tracks with specified friction levels.

Using the data from the PIARC international experiment, ISO TC 43 SC1 WG39 is developing a standard for using texture profiles to estimate texture depth measured by the volumetric technique. The required quality of the texture profile and the algorithm used to reduce the profile to the estimation of texture depth are being addressed. The results are much better when certain algorithms are used and these same algorithms also were found to provide the best results when used in conjunction with a friction measurement to calculate the IFI.

Since the IRRE was conducted in 1982, there have been significant improvements in road profilometry. As a result of these advances PIARC Technical Committee 1 has concluded that a new experiment should study the measurement of both longitudinal and transverse profiles and revisit pavement roughness measurement. The International Experiment to Compare and Harmonize Longitudinal and Transverse Profile Measurements is planned to take place in late 1995 in the United States and either Mexico or Canada. Plans for this experiment are under way and will be presented at the 21st World Road Congress in Montreal in September 1995.

Direction for Pavement Management Standards

Whereas efforts to harmonize friction measurements have proven successful, it remains to be seen how well the results will be implemented. On the basis of the experience gained from implementation of the IRI, agencies need concerted international and national encouragement to report the IFI and its two parameters, even if these quantities are not currently being used in their pavement management systems.

The initial World Bank project for harmonizing roughness measurements pointed out the shortcomings of some of the response-type roughness measurement systems and developed the IRI. The forthcoming experiment sponsored by PIARC will attempt to update and extend this to all profile measurements using the current technology.

The harmonization process should be extended to other measures used in managing pavements. Pavement distress measurements and units need to be redefined for automated imaging technology, and this should be a good opportunity for international harmonization, especially on cracking. Deflection measurement and pavement structural properties also require international harmonization. Although some of the efforts to standardize texture measures are motivated by the vehicle-pavement noise community, other noise-related measures should be investigated. Traffic data and vehicle classification procedures are also candidates for harmonization.

There has been progress in the standardization of procedures for various test methods, for example the U.S. effort to standardize the locked-wheel method for pavement friction. However, there is the potential for further standardization of other procedures such as the side-force and slip-friction testers. Although the methods are the same they are often conducted with widely differing operational conditions such as speed, tire size, and type. Any progress toward reducing the number of approaches to measuring the same phenomenon will greatly facilitate the harmonization process.

A by-product of harmonization attempts is that they often lead to an increased understanding of the phenomenon under consideration. Procedures that have evolved independently each have their merits, and the equipment developed to implement them can form the basis for improved measurements. However, different agencies and countries must combine their efforts to harmonize more aspects of pavement management. The goal is to unite our diverse approaches on a common path, allowing all the stimulus and competition that alternative technologies can have on the industry, and yet promoting wider exchange and pooling of knowledge through the use of harmonized measures. Harmonization is the road to universal benefit for pavement management.

REFERENCES

1. *Annual Book of Standards.* Vol. 04.03. American Society for Testing and Materials, Philadelphia, Pa., 1994.
2. Sayers, M., T. Gillespie, and C. Queiroz. *The International Road Roughness Experiment.* Technical Paper 45, World Bank, Washington, D.C., 1986.
3. Gillespie, T., M. Sayers, and L. Segel. *NCHRP Report 228: Calibration of Response-Type Road Roughness Measuring Systems.* TRB, National Research Council, Washington, D.C., 1980.
4. Sayers, M., T. Gillespie, and W. D. O. Paterson. *Guidelines for the Conduct and Calibration of Road Roughness Measurements.* Technical Paper 46, World Bank, Washington, D.C., 1986.
5. Paterson, W. D. O. Proposal of Universal Cracking Indicator for Pavements. *In Transportation Research Record 1455,* TRB, National Research Council, Washington, D.C., 1994.
6. Paterson, W. D. O., and T. Scullion. *Information Systems for Road Management: Guidelines on Data and System Requirements.* Technical Paper INU 77, Transport Division, World Bank, Washington, D.C., 1990.
7. *PIARC C-1: International Experiment to Compare and Harmonize Texture and Skid Resistance Measurements.* **PIARC/AIPCR Final Report**, Paris, 1995.
8. Henry, J.J., and M.C. Leu. Prediction of Skid Resistance as a Function of Speed from Pavement Texture. In *Transportation Research Record 666*, TRB, National Research Council, Washington, D.C., 1978.

What Are the True Costs and Benefits of Pavement Management?

W.R. Hudson, *University of Texas at Austin*
Ralph C. G. Haas, *University of Waterloo, Canada*

Various institutional issues related to the pavement management process are discussed in this conference. However, a major issue not adequately treated by many agencies is the comparison of the costs and benefits of implementing a pavement management system (PMS). This issue must be addressed more fully in the future if pavement management is to prosper.

Any such analysis must be done by individual agencies. It is not sufficient to be convinced that the benefits of implementing a PMS in an agency outweigh the costs; this must be demonstrated. This paper discusses general and specific aspects of benefit-cost studies. It also suggests methodologies to be considered for application by any agency.

Pavement Management Costs

There are several kinds of costs associated with pavement management. They include the following:

1. The direct costs of developing and implementing a PMS, plus the ongoing costs of acquiring and processing the PMS and keeping it current—that is, the cost of the PMS itself;
2. The actual expenditures on the pavements or the highway system; and
3. Indirect costs such as organizational changes necessitated by implementation of the PMS.

In reality, the effectiveness of a PMS is measured by the ultimate savings in real highway expenditures. The initial pavement investment and related costs must be considered along with savings and benefits that can be realized from the effective implementation of a PMS.

Many problems occur in determining the foregoing costs. Apparent costs can vary greatly depending on accounting procedures and methodologies within a given organization. Some highway agencies do not account for overhead or indirect costs when they perform work using their own staff, which is misleading in cost-benefit studies. The same activities done by contract or by outside experts clearly must include indirect costs in the final contract price for the work.

True cost information for evaluating the cost-effectiveness of a PMS is difficult to obtain. This is partially because few agencies have a fully implemented PMS, and fewer still have kept effective records of costs or made cost comparisons. In the case of the highway facility or pavement itself, the costs associated with construction are well documented but have usually been incurred for different sections over many years, making a basis of comparison difficult to obtain. More substantially, the costs of maintaining pavements are extremely difficult to define and very few highway agencies have truly good maintenance cost information defined by specific pavement section.

Rehabilitation costs are somewhat easier to determine but vary from time to time and place to place depending on cost accounting methods and contracting procedures in each agency.

Benefits and Costs Associated with a PMS

Tables 1 and 2 present a variety of benefits and costs associated with pavement management. They are categorized in terms of general benefits and benefits to elected representatives, senior management, and technical level people in Table 1. Costs and benefits particular to the state level are given in Table 2.

Some benefits and costs are quantifiable, whereas others are subjective and general. Benefits and costs must be measured on a common basis to be compared. However, benefits are often excluded from pavement management decision making largely because of the common agency philosophy that it is adequate to provide a safe and comfortable highway to serve the public. The idea of improved benefits accruing to the user based on better ride quality and lower vehicle operating costs has not been widely exploited in North America, although it is

TABLE 1 Notes on Benefits and Costs of a Pavement Management System

GENERAL	ELECTED REPRESENTATIVES	SENIOR MANAGEMENT	TECHNICAL LEVEL PEOPLE
Benefits			
Realize magnitude of the pavement investment Better chance of correct decisions Improved intra-agency coordination Improved technology use Improved communication	Justify maintenance and rehabilitation programs Assurance of best expenditure of tax funds Less pressure for arbitrary program modifications Objective answers to effects of lower funds or lower standards	Comparative view of network status (current and future) Objective answers to funding level effects on status, implications of deferred work and/or lower standards Justifying programs to elected representatives Assurance of best use of available budget Defining the "management fee" (percent of budget)	Improved recognition of various agency elements Increased awareness of available technology Improved communication between design, construction, maintenance, planning, and research Satisfaction of providing best value for available funds
Costs			
Software development Data collection, processing, storage, and analysis Actual operation of the system; computer hardware, staff Indirect costs	Some general costs Reporting Processing special requests	Developing, installing and operating costs of the PMS Data collection, processing, and analysis Staffing and organizational changes	Making changes in procedures Time and effort to upgrade skills; training costs

TABLE 2 Additional Costs and Benefits of State-Level Pavement Management

COSTS	BENEFITS
Establishment of a department task force/steering committee	Maintenance and rehabilitation needs and budgets; priority programming
Consulting services	Justification for funding requests
Data collection: agency personnel (engineers, technicians, equipment operators) and travel costs; training; equipment (vehicles, data loggers, distress survey devices, nondestructive structural test devices, surface friction measuring equipment, drilling and coring equipment, roughness measuring equipment); traffic control; traffic data acquisition	Effectiveness for expenditures through timely and appropriate action
Data processing (personnel, equipment, supplies, etc.)	User cost control through level of service; savings in user costs
Data analysis and reports (personnel, computers and peripherals, supplies, etc.)	More efficient usage of maintenance resources
System maintenance (personnel, equipment, etc.)	Improved planning, design, construction, research, performance models, safety, etc.
Training agency personnel	Improved knowledge of statewide pavement conditions and needs
Administration	Improved network serviceability

widely used in World Bank evaluations for developing countries. One of the very few quantitative assessments of the benefits and costs associated with a PMS is summarized in the next section.

Quantitative Assessment of Management Benefits and Costs

The true indications of the cost-effectiveness of the pavement management process involve the ultimate savings in real highway expenditures plus user cost savings. Because of the difficulties in documenting the costs and benefits associated with highway investments, it has been suggested that if the user cost savings alone indicate a substantial degree of cost-effectiveness for a PMS, the basis exists for quantitative justification of a PMS.

The Alberta, Canada PMS, initiated in 1980 and fully implemented by 1985, provided an excellent case application for testing the concept. It involves a network of more than 10 000 km of primary highways; a well-documented history of roughness, surface distress, and structural adequacy; and a rehabilitation budget that remained fixed at $40 million annually over 10 years. The costs of the PMS development and operation were also well documented, and it was believed that the vehicle numbers and annual mileage on the relevant network could be estimated within a reasonable degree of error. It was also believed that the asset value of the network could be reasonably well estimated and that vehicle operating cost relationships from the World Bank were applicable.

On the basis of this determination, user cost savings were calculated for an increase in average network serviceability, which occurred although the budget remained constant (in real terms it decreased; thus the analysis was conservative). The benefits-cost ratio (B/C) for savings compared with costs, depending on the assumptions used, was generally on the order of 100:1. Whereas this does not represent an exhaustive economic analysis, it appears to be a valid way to assess the value of a PMS. Moreover, it can be a very effective means for justifying a PMS.

A case study of the state of Arizona's PMS has also been included to illustrate the potential savings within the rehabilitation budget as a result of a PMS. These savings are real dollar savings achieved through selection of less costly rehabilitation strategies before a road reaches the point of no return.

The state of Arizona implemented a pavement management system in fiscal year 1981 on its 7,400-mi network of highways. The system replacement value was estimated at $6 billion, similar to that of Alberta, and the state rehabilitation budget of $52 million had doubled since 1975 as a result of increased needs (and therefore decreased condition). The PMS was developed in conjunction with a consultant to specifically address the budget for rehabilitation (or preservation, to use Arizona terms).

The main objective of the system was to develop a decision-making tool to maintain the network in its "most desirable condition within its budget." A secondary objective was to provide statewide consistency in policy and level of service and to protect the state's road investment. In fiscal year 1981 the state highway budget was set at $46 million on the basis of 5 years' prior pavement data and in an attempt to maintain the 1975 condition. By using the PMS to generate the entire rehabilitation program and by following through on its recommendations, the same level of service was reached with only $32 million, a real dollar savings of $14 million that can be largely, if not completely, attributed to the PMS.

Two reasons were cited for the cost savings:

1. The PMS selected rehabilitation strategies that were more preventive than corrective and selected roads before they reached the point of no return.
2. The strategies selected were less conservative (and therefore less costly) than the pre-PMS strategies because of the refinement of the performance prediction models that occurred during system development.

Additional Indirect Benefits

Significant indirect benefits of a PMS include the new knowledge created; the training provided for a substantial number of people (federal, state/provincial, local, consulting, contracting, etc.); and the awareness created among the public, legislators, senior administrators, and others about the increased value accruing from their expenditures. In other words, there is improved awareness of all the factors involved in the process of pavement management. This is illustrated by the teaching of such pavement management graduate level courses as FHWA's advanced course on pavement management during 1990 and 1991. The people taking the course became real advocates of PMS for a variety of reasons and returned to their organizations with renewed enthusiasm for providing good pavements.

Another set of indirect benefits of PMS that is difficult to quantify but important is the spin-off of technology to other infrastructure or facilities such as bridge management. Considerable attention began to be directed to the development of bridge management systems (BMSs) in the mid-1980s. A major impetus was provided by the knowledge and improvement in pavements arising from the application of PMS (*1–5*).

EVALUATION METHODOLOGIES

A number of potential methodologies exist for comparing costs and benefits of a PMS. In the many references available, the alternative methods range from discriminant analysis to general decision theories. Among the candidate methods are those briefly discussed in the following sections (*6–11*).

Benefit-Cost Criterion

Perhaps the best-known method for measuring the efficiency of an activity is the benefit-cost analysis, or more specifically the benefit-cost ratio. Efficiency in general is measured by this term because other variations, such as rate of return, are sufficiently similar to the benefit-cost analysis to have the same strengths and weaknesses. It has a sound foundation and provides a conceptually sound basis for effective comparisons. In practice, however, there are difficulties that tend to reduce its usefulness. The biggest drawback arises from the difficulty in breaking the factors into either the cost or benefit category; more specifically, it is difficult to actually measure the true cost and the true benefit. There are many intangible factors in benefit-cost analyses, which may be treated as follows:

1. They may be rated subjectively and included in the analysis.
2. When subjective scaling is not possible, verbal descriptions of intangible benefits may be provided in addition to the measured costs and benefits, and used as balancing aids by the decision maker.
3. They may simply be ignored; unfortunately, this is common.

In other words, if the analyst becomes preoccupied with the mathematics of the benefit-cost analysis and the measurable impacts, the tendency is to omit intangible benefits. The result can be an inflexible narrowness, which leads to a less optimal decision.

Another problem associated with benefit-cost analyses is the question of who pays the cost and who receives the benefits. For example, improved programming of maintenance funds may be a benefit of the PMS process that accrues to the agency and to the public. But cost may be seen by the maintenance director as a budget imposition. The cost may also involve a change in working assignments or the requirement that some agency personnel undergo additional training.

Excess Benefits

One of the many variations of cost-benefit analyses involves the calculation of the excess of benefits over costs. A simple case study comparison of this methodology involved a 373-mi arterial network for which the 10-year program list from a PMS optimization and a subjectively based needs study produced a total of $11 million in vehicle operating cost savings or net benefits for the optimized program. The annual budget for the program was only $10 million (*12*).

Goal Achievement

As one attempts to use the various methodologies for analyzing costs and benefits and reviews criticisms of benefit-cost and similar evaluation procedures, it is easy to become dismayed by the seemingly overwhelming complexity facing the decision maker. One also gains some appreciation for the position of the politician or the manager who must react to and give solutions for complex problems every day. One technique for broadening the evaluation and decision-making process is known as goal achievement (*13*). It involves the assessment of potential alternatives in terms of impacts compared with objectives. Quantifiable measures, which can be probabilistic, are used in this technique, although some subjective measures may also be used. In general, the procedure is to establish various criteria or goals for alternative methodologies. Quantitative measures or subjective estimates are then given to each criterion for each of the alternatives. These are standardized and compared on the basis of a total score of 100 to see which alternatives best achieve the goals of the decision maker.

Cost-Effectiveness Technique

The cost-effectiveness (C/E) technique is an alternative to the goal achievement procedure. C/E is actually relatively simple. Its basic premise is that better decisions will arise when clearer and more relevant data are supplied to the decision maker. No specific attempt is made to put all benefits and costs in common units such as dollars. The following quotation is relevant to this approach:

> What might be MORE useful is a technique for providing the kind of informational support for the selection among plans which recognizes the complex nature of these decisions. Such a decision supporting framework does not attempt to make decisions, but instead structures the information required for making a subjective, but systematically enlightened choice. At the same time, however, the framework must be sufficiently flexible to permit the adoption of more sophisticated techniques, such as analytical methods for realistically implementing benefit-cost analysis or ranking schemes, when such techniques are appropriate. (*14*)

Three criteria should be satisfied by any such framework (*13*):

1. Capability of assimilating benefit-cost and similar methodological results in addition to other informational requirements;
2. Strong orientation toward a system of values, goals, and objectives; and
3. Allowance for the clear comparison of compromises among objectives or making explicit the relative gains and losses from various alternatives.

Effectiveness is defined as the degree to which an alternative achieves its objective, which may be, for example, the area under the performance curve weighted by traffic volume and section length. The definition, by itself, helps to overcome one of the major objections to the benefit-cost approach in that goals are specified and are not covered by an all-encompassing benefit term.

The value of the C/E approach includes the following:

1. Simulation, to some extent, of the process by which actual decisions are made;
2. Allowance for clearer delegation of responsibility between analysts and decision makers; and
3. Easier provision of relative information, in an understandable format, so that the choice process is simplified.

Search and Choice

In the field of transportation system analysis, a technique alternatively termed Search and Choice in Transport Systems Analysis and Problem Solving Process (PSP) has been described for use in dynamic modeling of decision making (*6*). An outline of the process is shown in Figure 1.

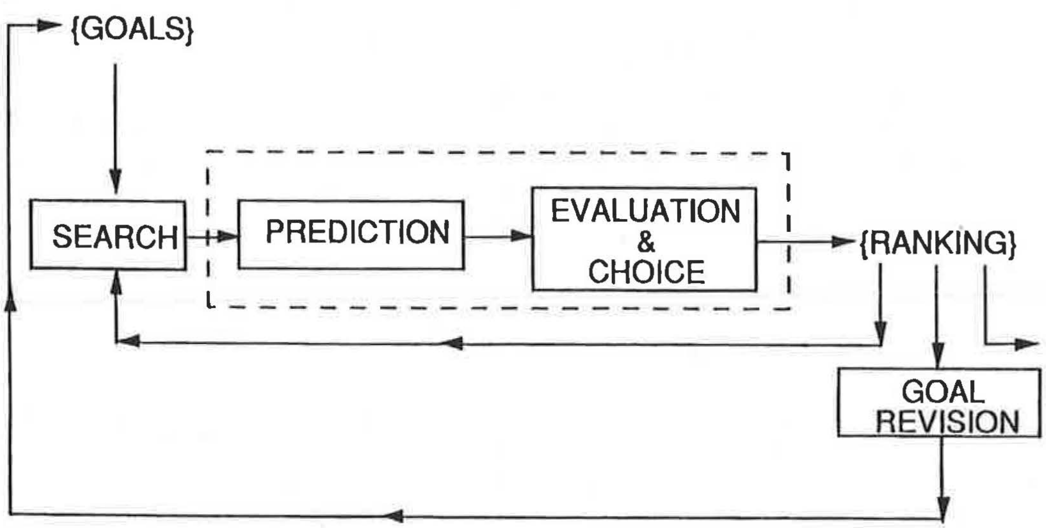


FIGURE 1 Basic cycle of PSP.

The focus of the PSP is on actions. Because search and selection procedures concern the basic processes of generation and selection of actions, these procedures are at the heart of the PSP. However, a variety of other activities must occur to allow search and selection to operate and revise the context in which they operate. Goal formulation and revision procedures are particularly important. Whereas the PSP seems to be valid for a decision maker dealing with various transportation systems, it apparently has not yet been applied to PMSs.

Statistical Decision Theory

We live in an uncertain world but tend to forget this and to become fascinated by quantitative data produced by complex models and elaborate calculations such as benefit-cost analyses. In truth, there is always uncertainty in such analyses. Uncertainties in transportation include at least three types: demand (such as traffic), technology, and goals. No matter how elaborate the prediction models or how much data are collected, there will always be uncertainty about predictions of traffic, pavement performance and life, and maintenance costs and inflation. Statistical hierarchical decision processes are outlined by Manheim (*7*). He has developed a statistical decision approach to complicated transportation planning theories, but it does not appear that the methodology is particularly applicable to the PMS process.

Discriminant Analysis

Discriminant analysis and classification are multivariate techniques concerned with separating distinct sets of objects and allocating new objects to previously defined groups. Discriminants are sought whose numeric values are such that the collections are separated as distinctly as possible. The goal of classification is to sort objects into two or more labeled classes. The emphasis is on deriving a rule or rules that can be used to optimally assign a new object to the labeled classes.

A function that separates may serve as an allocation and conversely an allocatory rule may suggest a discriminatory procedure. In practice, the distinction between discrimination (or separation) and classification (or allocation) is not so clear. One of the objectives of conducting discriminant analysis is to provide the basis for a classification rule.

The methodology of discriminant analysis, while useful in dealing with a large number of objects, does not appear to be appropriate for evaluating the costs and benefits of the pavement management process (*8*).

Other Methodologies

Many other methodologies have been used for decision making. Among these are found terms such as "benefit/risk analysis" and "preference and value tradeoff." However, these other methodologies are not examined in this paper.

Any evaluation used for testing the benefits and costs of the PMS process must be meaningful to the decision maker. After all, the purpose of any such study is to present information useful for convincing decision makers to implement improved PMS methods. This concept should be given full attention in all PMS agencies.

CONCLUSION

Three of the methodologies outlined in the preceding sections may be useful in determining the value of a PMS. Certainly benefit-cost analysis is a strong candidate because of its potential impact in comparing costs and benefits for a sample network. C/E techniques also bear additional study.

The general concept of goal achievement methods also bears consideration. It is not yet clear how the method might be applied since it involves an examination of the goals of decision makers on an individual basis. This might be handled with hypothetical examples if interviews with two or more decision makers could be arranged to gather information.

Finally, it is incumbent on those involved in the pavement management field to develop clean guidelines for any agency to use in determining the quantifiable and qualitative benefits and costs of a PMS. Otherwise, the value of a PMS to an agency is open to question.

References

1. Hudson, S.W., R.F. Carmichael III, L.O. Moser, W.R. Hudson, and W.J. Wilkes. *NCHRP Report 300: Bridge Management Systems.* Transportation Research Board, National Research Council, Washington, D.C., Dec. 1987.
2. Hudson, W.R. *Approaches for Comparing the Costs and Benefits of Improved Levels of Pavement Management.* ARE Report. Contract DTFH61-87-P-00554, 1987.
3. Hudson, W. R., C. Boyce, and N. H. Burns. *Improvements in On-System Bridge Project Prioritization.* Research Report 439-1. Center for Transportation Research, The University of Texas at Austin, Jan. 1987.
4. Hudson, W. R., N. Burns, R. Harrison, and J. Weissmann. *A Bridge Management System Module for the Selection of Rehabilitation and Replacement Projects.* Preliminary Report 439-4F. Center for Transportation Research, The University of Texas at Austin, Nov. 1989.
5. Hudson, W. R. Development of Managing Systems Around the World. *Proc., Engineering Foundation Conference on Managing America's Aging Bridge Systems: Issues and Directions,* New York, 1989.
6. Manheim, M.L. Search and Choice in Transport Systems Analysis. Presented at the 48th Annual Meeting of the Transportation Research Board, 1969.
7. Manheim, M.L. Decision Theories in Transportation Planning. In *Special Report 108: Highway Engineering Economy,* Highway Research Board, National Research Council, Washington, D.C., 1970.
8. Lee, H., W.R. Hudson, and C.L. Safaf. *Development of Unified Ranking Systems for Rigid and Flexible Pavements in Texas.* Research Report 307-4F. Center for Transportation Research, The University of Texas at Austin, 1985.
9. Edwards, W., and A. Tversky. *Decision Making.* Penguin Books, Baltimore, Md., 1967.
10. Dyckman, J. Planning and Decision Theory. *Journal of American Institute of Planners,* Vol. 27, 1961.
11. Morris, W.T. *The Analysis of Management Decisions.* Richard E. Irwin, Inc., Homewood, Ill., 1960.
12. Smeaton, W.K., M.A. Karan, C. Bauman, and G.A. Thompson. Case Illustration of Long-Term Pavement Management and Update. *Proc., Canadian. Technical Asphalt Association,* Montreal, Quebec, Canada, Nov. 1981.
13. Dickey, J.W., et al. *Metropolitan Transportation Planning* (second edition). Hemisphere Publishing Corporation, McGraw-Hill Book Company, New York, 1983.

Charge to the Conference

Carl L. Monismith, *University of California, Berkeley*

As we have heard, this is the third in a series of international conferences on pavement management and it has been 7 years since the second conference. This is a long time between opportunities to exchange information at the international level in this rapidly developing field. Accordingly, it is appropriate in these opening sessions to ask where we are now and what direction we should take in the future.

Moreover, since pavement management is of importance worldwide, and this conference truly is international in representation, we must take advantage of this opportunity to forge international links of cooperation to ensure that important developments, wherever they occur, can be effectively used by the world community.

In considering what direction pavement management should take in the future, a number of factors should be considered, all of which are key to improved pavement management. These factors are as follows, in no order of priority since all are important: performance models, traffic data, data acquisition, user costs, optimization, and construction.

Performance Models

To do a better job in performance prediction, it is important to shift from empirical and regression models to those that are mechanistically based. Whereas there are some modes of distress for which it may not be possible to develop mechanistically based performance models, a number of the major modes of distress can be estimated with reasonable accuracy. These include load-associated (fatigue) cracking in both asphalt concrete and portland cement concrete pavement and estimation of rutting and low-temperature cracking in asphalt pavements. Results of the recently completed SHRP asphalt research program provide a sound basis for improved models for asphalt pavements.

With improved understanding of the performance of materials, it is also possible to include consideration of reliability in the estimates of performance. Inclusion of this consideration will most certainly make decisions regarding maintenance and rehabilitation more cost-effective.

Traffic Data

For performance models to work effectively in the pavement management process, realistic traffic data are required. For trucks, these include (*a*) axle loads and configurations, (*b*) repetitions of the various loadings, and (*c*) tire pressures.

In the United States the acquisition of traffic data has improved at the state level, in part because of improvement in weigh-in-motion methodologies and initiation of the LTPP program of SHRP. Because there is a paucity of local traffic data, efforts must be made to improve such information at the local governmental level.

Data Acquisition

Standardization is required in the data acquisition area. This includes standardization in what to collect and in how to collect it. A number of activities at this conference are associated with this aspect of pavement management, and I hope that clarification and guidelines will result from the deliberations this week.

In the United States, this standardization is required to permit comparisons of needs across state boundaries. This is true also at the local level. An example of the latter is the pavement management activity by the Metropolitan Transportation Commission (MTC) for the nine counties and associated cities in the San Francisco Bay Area of northern California.

I am certain that concern for standardization is a high priority among the members of the European community as well. Moreover, for the developing countries to effectively improve their road networks, such standardization is necessary.

User Costs

User costs play an important role in pavement management activities. One definition of pavement management encompasses minimizing agency costs (for maintenance and rehabilitation) while optimizing benefits to the users. Presumably this means attempting to reduce user costs. Whereas the 1980 workshops on pavement management conducted for FHWA by the Transportation Research Board (with Fred Finn as chairman of the Transportation Research Board task force) indicated that the definition of user costs was a high-priority research item, little has been done in this area since the recommendation was made.

One of the major problems concerning user costs is how best to incorporate them into the pavement management process. Many examples have been presented to demonstrate that consideration of such costs may overwhelm maintenance and rehabilitation decisions because of the relative magnitude of the user costs. Nevertheless, we must find a reasonable way to incorporate this parameter in pavement management decisions.

Two relatively simple examples emphasize the importance of this. The first is related to user delay costs associated with premature maintenance and rehabilitation activities. If improved management decisions are made that can forestall the development of early distress, it is obvious that user costs will be significantly reduced.

The second is related to the truck-pavement interaction problem. By changing the level of roughness at which rehabilitation is accomplished, for example by rehabilitating at the lower level of tolerable roughness, two benefits may be accomplished. The first is related to the influence of pavement roughness in the packaging of goods for transport to minimize damage to the goods and thus lower costs to the public; the second is related to the potential damage to the pavement by trucks, which is exacerbated as roughness increases. With improved user cost data, the level of roughness before maintenance and rehabilitation might be reduced, resulting in substantial savings both to highway agencies and the trucking industry. These examples emphasize the importance of directing considerable thought to how best to incorporate user costs in the management process.

Optimization

For pavement management at the network level to be cost-effective, optimization is required to ensure that the resulting decisions for maintenance and rehabilitation truly define an optimal solution. I view true optimization as embodied in systems such as that used by Arizona. This represents the type of process with the potential to truly provide optimal solutions depending on the resources available—both time and money.

Warranted Construction

An important consideration in the New Frontiers session is the consideration of construction activities designed to improve pavement performance. One example is the use of warranted construction. With warranted construction by the contractor, the time interval between rehabilitation activities may be stretched out, thereby reducing user costs resulting from premature maintenance and rehabilitation activities. It is likely that the overall cost to the highway agency will be reduced as well—although one might argue that the initial construction costs might be larger—because of the improved performance. This is only one example of how construction considerations can lead to improved pavement management.

Summary

This charge has addressed a number of factors. I sincerely hope that all of us will evaluate what has been presented here, including the factors I have enumerated. When we return to our respective countries, I urge that these evaluations serve to spur our efforts for improvements and that we come together again, in less than 7 years, to report our significant advances.

WORKSHOP SESSION 5

How To Market a Maintenance and Rehabilitation Program to Decision Makers and Senior Management

Frank Francois (Moderator), *American Association of State Highway and Transportation Officials*
Eric G. Johnson (Recorder), *Alaska Department of Transportation and Public Facilities*

Frank Francois, Executive Director, American Association of State Highway and Transportation Officials (AASHTO), opened the session, which dealt with implementation and institutional issues. Specifically the session provided information on how those using pavement management systems (PMSs) should present the results to decision makers and senior management. The session used two role-playing situations to simulate PMS presentations to county and state officials. The audience consisted of citizens attending a public meeting. The officials had been enlightened enough in the past to fund PMS implementation, and the PMS staff had completed results of the first cycle of PMS recommendations. The question was, How do you market the recommendations to those above you? After the PMS presentations, senior national, state, and local officials discussed what they need from pavement management.

Before the presentations, Mr. Francois stated that PMS is political, because decisions are made by elected or appointed political officials. They function to set policy on highways. They provide funding and frequently divide the budget between operating and capital budgets and establish the basic framework for decision making. The officials also deal with many other issues such as criminal justice, public health, education, and economic development; therefore, people involved in highways and transportation must fight for the time and attention of these officials to get problems solved.

Local/Regional PMS Presentation to Board of Supervisors

Characteristics of the local/regional level include jurisdiction over local streets, collectors, and minor roads. The highway agency is directly responsible to elected officials, either the mayor or members of the county or city council. The officials worry about activities such as those listed previously, as well as roads and streets. Local government officials tend to think short term, from election to election. All decisions they make are concerned with things that are worthy of the press—preferably a project with a ribbon cutting attached to it. This usually means new construction, not rehabilitation and maintenance. Maintenance is always the first to be cut in times of shrinking budgets.

Margot T. Yapp, PMS Engineer for Monterey County, made the first presentation—local/regional. Members of the county board of supervisors were played by John German, Director of Public Works for the city of San Antonio, Texas; Jimmie Schindewolf, Director of Public Works, city of Houston, Texas; and Bill Whitcomb, Pavement Management Engineer for the city of Vancouver, Washington. Mr. Francois acted as chairman. The board's county, Monterey, is urban and rural with 350,000 people. Its traffic consists of trucks and tourism. It has 1900 km of highways.

Margot T. Yapp: I am here to present Monterey County's Phase 1 pavement management system implementation. The department began discussing the need for a PMS in early 1993. We have just recently completed implementation. To recapitulate: Why do we need a PMS? To answer the following questions: (*a*) What do we have? (*b*) What condition is it in? (*c*) When do we fix it in the 5-year capital improvement program? (*d*) Where do we fix these roads? (*e*) How much will it cost to fix them? (*f*) What is the best way to spend maintenance and rehabilitation funds? (*g*) How do we prioritize the projects? In the past we had no rational method to answer these questions.

The county has 1,270 centerline mi maintained within the county. Phase 1 included 160 mi of arterials and collectors. Phase 2 has 1,110 mi of local residential subdivision roads. We expect to finish Phase 2 implementation in 1995.

We use a pavement condition index (PCI) with a scale of 0 to 100, 100 indicating excellent and 0 indicating failed. If the pavement condition is from 0 to 25, we reconstruct; 25 to 55, we place a thick overlay; 55 to 70, we place a thin 1.5-in. overlay or chip seal; and 70 to 100, we do preventive maintenance, including crack sealing or slurry seal.

The overall pavement condition currently has a 71 PCI, which is good to very good. However, we have several problems ahead. Our budget analysis shows that we will need $12.3 million for 1994–1999 just for Phase 1—160 mi. You will recall that the total county mileage is 1,270. Of the $12.3 million, 89 percent is needed for overlays or reconstruction, 5 percent for chip seals, and 6 percent for emergencies.

We looked for reasons for these needs. We found that we have had no overlays for 10 years, and our chip sealing program, which had been reduced significantly, was eliminated in 1994. The 1989 earthquake used substantial reserve funds. New congestion management has taken significant funds as well. We also lost $2 million a year starting in 1993, diverted to the general fund. State and federal contributions have also been reduced.

The PCI is currently 71. If no funds are spent in the next 5 years, the PCI will drop to 55. At our existing budget level of $5 million to $6 million over the next 5 years, we will have a gradual drop to 65. Maintaining our existing condition of 71 will require $9 million to $10 million. Achieving our goal of a PCI of 85 will require $12 million over the next 5 years.

I would like to conclude by saying that our shortfall of $1.5 million a year to maintain the existing condition for Phase 1 is showing that history is catching up with us. We need to start overlay and reconstruction and increase our chip sealing program. And finally, we need to find more funds.

County Supervisors' Questions

Frank Francois: This comes as a shock to us. Do any members of the board want to ask questions?

Bill Whitcomb: Where are the existing funds coming from, and where are they expended?

Margot Yapp: Gas tax revenues are $600,000, STP funds are $250,000, and other sources are $200,000 per year. A lot of this money is used in operations.

Bill Whitcomb: So you have no real capital program?

Margot Yapp: Yes.

Bill Whitcomb: What does it mean to the populace to let the condition deteriorate to 64 in the next few years and to look for ways to fund then?

Margot Yapp: The county network is in overall good shape, with some parts needing reconstruction because of increased agricultural traffic. The overall comfort to the public is good now. If we were to let the condition deteriorate to 65, we would see a much greater area needing arterial repair. This affects 70 to 80 percent of the traffic using the arterials.

Jimmie Schindewolf: Crime is on the increase, and we need to hire more police and to build jails. What is more important: more money for crime or more money for streets?

Margot Yapp: I can't answer that. The board is best suited to set policy. I'm just here to follow.

Jimmie Schindewolf: How many years before we reach the point of no return? Budgets are tight again this year.

Margot Yapp: There is no point of no return as long as there are sufficient funds to bring us back. However, because we have not done overlays for 10 years, I believe that this is the year we have to do something. The life expectancy of our network has just about been reached.

John German: I'm new to this business. What is the definition of each type of surfacing?

Margot Yapp: Preventive maintenance crack sealing is done on cracks greater than ¼ in. The cracks are cleaned and sealed. Slurry seals, a thin mixture of sand and asphalt, are spread over an area and seal smaller cracks. Thick or thin overlays are layers of asphalt concrete: thin being a minimum of 1½ in. and thick being much thicker. In reconstruction we remove the surface and sometimes the base course.

John German: I represent the older part of the city. People call about their "favorite" potholes. I have only 4 years on this board, and I really want to see potholes fixed. I am looking at the 1,100 mi in Phase 2 and wondering how I am going to fix those in my area. Is there a new funding source in this regard?

Margot Yapp: Increases in gas taxes or sales taxes are under study right now.

Frank Francois: This PMS was pushed down on us. Do we really need it? Who mandated the system? Who set up PCI?

Margot Yapp: The Corp of Engineers put together a panel of engineers that created the original qualitative scale from 0 to 100.

Frank Francois: You think this is a meaningful scale then?

Margot Yapp: Yes, I do.

Frank Francois: Do we have to fix all 160 mi in Phase 1, or can we do part?

Margot Yapp: The PMS identifies a list of projects at various lengths from 1 mi to several miles long.

Audience Questions

Audience: How much does it cost to take a 1-mi road and increase its life by 1 year?

Margot Yapp: I don't know.

Audience: Each year the system loses 1 year of remaining life. What is the cost of getting this back? You have 1,270 mi in the bank. If you continue to do chip seals and thin overlays, you lose your investment. Can you calculate the remaining life of your system?

Margot Yapp: Yes. We tried to talk to the board and the public about remaining life, and all they were concerned about was saving time in transit. I believe remaining life is too technical at the board level. I want to emphasize that for roadway networks existing on borrowed time, the true cost to the public of deferring maintenance on a rougher road is two to three times that of deferring maintenance on a smoother road. A PMS should include all costs, not just agency costs. Also, I recommend that a dedicated fund be established for rehabilitation and maintenance and that transporters pay a user fee into this fund.

Audience: Every year that we defer maintenance and rehabilitation we pay three or four times these costs in the future. Do your numbers show this?

Margot Yapp: Yes, they do.

John German: Do you think we can ask the heavy vehicles—truckers and bus companies—to pay their fair share of damage to the roadways?

Margot Yapp: If the transporters can be shown the benefits—lower costs—of better roads, they will agree to pay higher fees.

Audience: Why not spend $12 million just for the first year and get us up to an 80 condition level, and let us go to the no-funding scenario? I see we drop only eight points over the next 4 years, which is still above our present condition.

Margot Yapp: I'm afraid our staff will not be able to accommodate $12 million worth of work in 1 year, then have no work for 4 years.

Audience: How much are we paying compared with adjacent counties?

Margot Yapp: Santa Clara County passed a transportation bond several years ago, and we did not. That is why we are looking at increased costs now.

Audience: When I was going to school, I used to carry a water bucket to gangs of convicts doing road maintenance. Looks like a win-win solution to me.

State/National PMS Presentation to a Transportation Commission

State highway officials usually are appointed to policy boards that are responsible to elected officials. State highway networks usually comprise principal arterials. These networks cover large areas, connect large and medium-sized cities, and connect to areas outside agency jurisdictions. The boards have some degree of freedom, and members tend to think in the long term—5-, 10-, and 20-year programs. They are concerned solely with transportation issues.

Brian McWaters, Pavement Design Engineer for the state of Iowa, made the presentation. Members of the Iowa Transportation Commission were played by Denise Evans, Regional Director for Operations, Ministry of Transportation, Ontario, and Byron Blaschke, Former Deputy Executive Director, Texas Department of Transportation.

Brian McWaters: Good afternoon. We are going to talk today about System A and Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) funding. Because we have been transferring funds from other categories, the commission has become concerned. What happens to the system if we spend $40 million or $50 million a year instead of the $55 million we currently spend?

Iowa is a medium-sized state with many farms and some factories. It has a large capital city of 300,000 and a few medium-sized cities. System A, consisting of the main routes, has 780 centerline mi, or 1,560 lane mi. We started building the system in the late 1950s and completed it in the mid-1980s.

What does our system look like in terms of age? A vast number of routes are becoming quite aged. Every road more than 5 years old had a 20-year design life. Due to the growth in traffic, all these routes have reached the end of their design lives. Having 1,600 mi of Interstate routes with a 40-year design life means we have to replace 40 mi per year. We currently operate under the policy of fixing the worst routes first. I-80 handles 30,000 vehicles per day, 30 percent of which are trucks. The trucks are wearing out the pavement, not the environment. This is more than 2.5 million ESALs a year. An ESAL is the equivalent damage of an 18,000-lb single-axle load.

What is the condition today? The worst areas all have repair programs, but because of a lack of funding many of these projects have been pushed back. If we use only ISTEA money on System A, the system will deteriorate. Maintaining the system will require $78 million a year over the next 5 years. If the average condition is 60, there will be some above and some below, which may not be acceptable.

Transportation Commission's Questions

Denise Evans: Does your map of condition, showing the worst areas, compare to your map of age?

Brian McWaters: They are not directly related.

Denise Evans: Are your funding levels related to age or to condition?

Brian McWaters: Condition. The older pavements that are in good condition could have problems to come.

Denise Evans: What about traffic growth?

Brian McWaters: There is 4 percent growth per year in trucks on System A, which translates into a 9 percent growth in ESALs.

Frank Francois: When the governor met with us, he said he wanted to be assured that the highway system will support economic development in Iowa. How much do we need to spend to assure him of that?

Brian McWaters: That depends on what you consider as acceptable. If you want to maintain pavement condition above 60, we need to spend $78 million a year. "Worst first" is not the best scenario, because we can preserve the system by doing a less costly rehabilitation sooner.

Byron Blaschke: If we follow this concept, how do you propose that we explain to the citizens of Iowa why we are not doing the worst first?

Brian McWaters: News releases, and you can explain it at your public meetings.

Byron Blaschke: It is my understanding that with the North American Free Trade Agreement, the weight limits on trucks may increase. What would happen?

Brian McWaters: A lot. You would see an increase in the downward slope of the pavement condition with time at the current budget level.

Byron Blaschke: Can you document the annual traffic increase and the resulting damage increase and condition drop? Do you have data that we could provide to the federal government?

Brian McWaters: We are developing those data now.

Byron Blaschke: Why 60 for PCI?

Brian McWaters: That was selected by your commission based on funds allocated on past performance and traffic levels.

Frank Francois: How do we compare with Minnesota?

Brian McWaters: It is hard to say because Minnesota does not use the same condition rating.

Denise Evans: How have we been doing with our current levels?

Brian McWaters: We have been increasing the pavement condition on I-80 by doing reconstruction. It was rated as one of the 10 worst highways in the nation.

Denise Evans: Will we see the long-term cost unit costs go down by switching from worst first?

Brian McWaters: Not necessarily. We expect costs to go up.

Audience Questions

Audience: A question to the commission: Is the time frame of the presentation you just saw what you would like to see? Were the data detailed enough for you to make decisions?

Byron Blaschke: There is no simple answer. It depends on the previous exposure by the commission to PMS. If there has been previous exposure, what Mr. McWaters has presented is sufficient. The key is to know your audience. As to the time frame, the 5-year window is probably a good one. You may want to look farther into the future. This presentation is a part of the pie. You really need to look at the total situation.

Audience: How much life relates to levels of PCI? PCI is a point estimate in time. I think that by looking at remaining life versus time, you can see what is happening to your investment. The PCI is a composite number, which camouflages what causes a pavement to die.

Brian McWaters: We use the PCI because there are different types of remaining life: structural, functional, and so on. The PCI combines these. We train the commission so they do understand.

Audience: If the truckers cause the damage, why don't we make a road a toll road and charge them by weight? Pennsylvania does it.

Brian McWaters: That is not the commission's policy.

Audience: As a trucker, what is going to happen to vehicle costs as the PCI drops? What we have here is only the agency costs.

Brian McWaters: PCI includes ride, so roughness is considered. This system is just for disseminating agency resources.

Audience: I am a pavement engineer for Sheffield, England, a town of 300,000 people, with 2,000 mi of roads. My experience has shown that you have to give the politicians the hard facts. First, note the value of the asset: Ours is $2.5 billion that elected officials are responsible for. This is the costliest category, the one we do the most work on. Twenty percent has 87 percent axle damage on the system. Show overall spending broken down by area. It is vital to compare the system to the national. We are in the bottom 30 percent on dollars per kilometer. Against adjacent authorities, we are the lowest. Since 1986 there has been a 50 percent reduction in the real value of the budget. There has been a fourfold increase in the number of complaints. The number of accidents has increased. Emphasize residual life: Nail it into the politicians' minds how much life they've got in their roads. Thirty-six percent of our bus lines are in worse condition than the agreed-on standard. Bus lines have refused to send buses into certain areas. These are cold, hard facts politicians can remember.

What Top-Level Executives Expect from a PMS Presentation

Byron Blaschke made the presentation. He is former deputy director of the Texas Department of Transportation, with at least 12 years of experience in PMS, and he has been an advisor in other countries.

Byron Blaschke: Senior management covers a wide range—from the chief engineer all the way up to a legislative committee or governor. What are the needs of senior management?

1. Sound design, construction, maintenance, and rehabilitation policies. Are you using state-of-the-art concepts? Are you using cost-effective alternatives?
2. Sound basis for characterization of pavement conditions. Is it understandable? Can you convey it? Is it realistic?
3. Pavement conditions: current, predicted, and desirable. What are the trends with the resources that have been committed in the past few years? What are the predicted conditions under certain scenarios? Why is a certain condition level desirable?
4. Rational basis for allocating funds and resources. Regrettably, senior-level management does not always use a rational approach for allocating funds. The higher you go up the management ladder, the less rational and more political the basis for making these decisions becomes. The PMS engineer should be ready to give management a good rational basis.

It comes down to two basic questions:

1. Are we properly designing, constructing, maintaining, and rehabilitating our pavements?
2. Are we allocating sufficient funds for maintenance and rehabilitation?

Size and weight limits are important issues for the PMS engineer. You need to have good information and convey it to decision makers. And the higher you go, the more difficult it is because management becomes more susceptible to lobbying from the trucking industry.

The following basic factors should be remembered:

1. When the budget must be reduced, maintenance is often the first area to be affected.
2. Ribbon cuttings are not scheduled for rehabilitation and maintenance projects. There is no political excitement regarding rehabilitation and maintenance projects.
3. Good, sound pavement management often defies common perceptions and common sense. The public's perception of pavement deterioration is not always on target.

Information must be tailored to your audience:

1. Chief engineers have some experience in pavement considerations and may appreciate the importance of maintenance and rehabilitation.
2. Chief administrative officers often are not engineers and do not have technical backgrounds.
3. Commissioners generally are political appointees, with no realization of PMS concepts.
4. Legislators may have similar backgrounds, but have less time to consider PMS because of competing interests.

Make a different presentation for each level of management. You've got to "de-engineerize" the facts. For instance, Texas Department of Transportation public affairs people ask us questions they believe commissioners and legislators would ask, as preparation for our presentations.

Recommendations are as follows:

- Keep it simple. Relate to the knowledge level of the audience. Meet with the commissioner before the meeting to find out the sorts of questions that will be asked. Conduct workshop sessions to raise the level of knowledge.
- Keep your objective in mind. Don't forget why you are making the presentation. Make sure your presentation supports that objective.
- Ensure that you have support within your own organization. Local engineers and employees can easily undercut the creation of the program. Legislators can call local engineers and get opinions that can destroy the system.
- Recognize political realities, and work within these considerations. What are the politics of your upper-level management?
- Don't forget credibility! You've got to build the credibility of your information. If there is any doubt, your audience will not believe you.

Engineers have not had training in marketing, and that is what we are doing. Rely on in-house public affairs people. Learn how to simplify the graphics and how to hit your target—the audience. No rules exist. Be careful of using others' methods. These methods may have worked for them but their audiences may have been different. Marketing is a very "unengineering" approach, but there is a need for it in PMS. It is incumbent on you to use marketing to make effective presentations so that sound, rational decisions are made by upper-level management.

Denise Evans: We are marketing maintenance and rehabilitation programs, not pavement management systems. You are marketing the need for funds. Ontario has no dedicated funds; we have to compete with other programs for general funds. State your case to administrators in terms of allocating funds. This becomes more complex because legislators may have less experience because of shorter tenure. It is important that the data be quantified so that decisions can be made across programs. The Canadian federal government does not have dedicated highway funds.

Bill Whitcomb: The key thing is credibility. The populace is intimately familiar with its portion of the road system. If there is any inaccuracy, you will have a problem selling the recommendations. Another problem is continuity. When you present policy to one person and that person leaves, all the information leaves with him or her. You must continually train new people.

Jimmie Schindewolf: Houston has difficulty with keeping council members interested in long-term problems because of members' term limitations. We have developed neighborhood standards programs. By rehabilitating all parts of a given neighborhood, the citizens become used to the desired standards. They then support tax increases by the council to maintain these standards. That's what elected officials want—citizen support. PMS is technical, but it can be made to be understood by citizens.

John German: San Antonio has 1 million people and 3,000 mi of street. We are able to rehabilitate 125 mi every year at a budget of $15 million a year. We figure we should be doing 375 mi a year at a rate of $45 million a year. Where do we find the money? In the early 1980s we had an aggressive PMS; however, in 1985 we ran out of money, and no maintenance work was done for 7 years. We had to start over again with new data. Without consistent funding we will go from doing nothing to reestablishing PMS. Also, the local level understands fixing potholes but does not understand the sophistication of a PMS.

Audience Comments

Audience: One thing I heard makes me uneasy: The political process is not rational but emotional. I would like to propose that it is one of the most rational of processes. We have the wrong perception of the process. We always view the political process as a unified marching of forces to a unified decision. It is not like that. It is achieved by constant competition of pressures and forces from the public. As such, the citizens ask reasonable questions: You want money from me? Prove to me that it is crucial. What am I getting for it? What's in it for me? Can you see anything more rational than these three points? We always whine about the political process. We have good management systems, but the patient died. We have to study and understand the political process. In Ontario, transportation ranks as number 11. Many other issues are more important.

Audience: The reason transportation ranks number 11 is because we have done a good job. People don't complain unless there are problems.

WORKSHOP SESSION 6

Location Referencing and Global Positioning Systems/ Geographic Information Systems for the Information Technology Age

David R. Fletcher (Moderator), *Geographic Paradigm Computing*
Jack H. Springer (Recorder), *Federal Highway Administration*

Location referencing is of vital importance to pavement management. When we talk about location referencing, we are actually talking about two subjects. One is a location referencing method that uses a set of field procedures to identify the location of any point. The other is a location referencing system (LRS), which uses a set of procedures to manage location referencing. David Fletcher stated that the objective of an LRS is to designate the geographic position of specific locations on and off the highway. There are three types of LRSs: geodetic, which is based on latitude and longitude; geographic, which is based on mapping; and linear, which is based or locating by milepost or other linear measuring device.

The presentation of two papers on location referencing systems was followed by a panel discussion and the presentation of a third paper.

Paper 1: Improvements to Utah's Location Referencing System to Allow Data Integration

Richard A. Deighton, Deighton Associates, and David G. Blake, Utah Department of Transportation

Richard Deighton began by discussing how important location referencing is to an organization. A question we are always asking is, where are my data? Where are data in the field, and where are they in my data base? Without a working LRS we may be able to locate our data in the field but may have problems in our data base or vice versa.

In location referencing there are three important items: system, method, and address. The system is how we relate one location to another; the method is how we locate a point in the field; and the address is a string of characters that uniquely identifies a location. Mr. Deighton closed out his discussion by describing the types of location referencing methods: mile point, milepost, reference point, reference post, and spatial.

Mr. Deighton's description of location referencing enables us to understand the problems that Utah was faced with, which were described by David Blake. Utah is upgrading its pavement management system (PMS), and as part of this upgrade the state wanted to straighten out its LRS. Utah officials had determined that, within the department of transportation and other organizations that supply data to the PMS, there was more than one referencing method in use. These different location referencing methods made it difficult to look at data at one point on the road. Officials looked at adopting one method but determined that a single method was impractical; therefore, they decided to adopt an LRS that could accommodate the various location referencing methods used throughout the state. To develop the system, the state established a task force made up of the users. Involvement of users is very important to ensure acceptance of your referencing system. To develop an LRS, you need personnel and funding, and to acquire these you need the support of upper management.

Paper 2: Establishing a Link/Node Referencing System in North Carolina

Mary C. Opperman and Shie-Shin Wu, North Carolina Department of Transportation

Mary Opperman and Shie-Shin Wu spoke on establishing an LRS in their state. The state previously had used a mile-point system but had determined that this was not adequate. The system did not accommodate change. They studied various location referencing methods and determined that the one best suited to North Carolina was the link/node method. Unlike Utah, which discovered that various methods were being used throughout the state, North Carolina was using only the mile-point system; therefore, adopting a new system was not traumatic. The major problem in implementing the new system was that it was very labor-intensive. The old system had to be manually reviewed and cleaned up.

Although Utah and North Carolina reached a different decision concerning the location referencing method and system to be used, they both used the same approach to solve their problems. They examined their current systems and determined who was using them. Having determined their needs, the states chose systems that matched their needs. Therefore, if we select location referencing methods that meet our organizational needs and develop a system that relates these methods to one another, we will always know where our data are located.

Paper 3: PMS GIS in South Carolina

Alan Cheetman, PMS, Inc., and Bill Beck, South Carolina Department of Transportation

South Carolina acquired a PMS management system from PMS, Inc., and was looking to integrate its PMS into a geographic information system (GIS). Officials began by describing the use of a PMS and GIS in the organization. PMS and GIS can be integrated three ways. The first is total integration, where the PMS and GIS share the same data base. The second method is for the GIS to is import data from the PMS. The third method is for the PMS to import maps from the GIS. PMS and GIS software plus any organizational restraints will help determine which method of integration is best.

What does the state want and need out of its systems? When these questions are answered, the state should be able to properly integrate PMS and GIS or choose an appropriate LRS.

Panel Discussion

A panel discussed PMS and GIS integration. A comment that must be considered was made by Bill Paterson of the World Bank. We must watch out how we use the word "system." We easily apply the word to a variety of things. The first two papers presented at this session were about location referencing methods and systems. What many people call an LRS is actually a method. A data base is not a PMS. Neither are performance models, but when you combine the different elements you establish a system. But "system" is not the only word we misuse, and we must watch our use of all words.

Institutional Impacts of Implementing the Integrated Road Management System

Junius Hutabarat, *Government of the Republic of Indonesia*

The Indonesia road network is spread over 17,000 islands that have a land mass of 1 948 732 km^2. The network has three elements:

- National roads, 17 800 km;
- Provincial roads 32 250 km; and
- District roads, 181 200 km.

The route network serves more than 184 million people, about 35 percent of whom are concentrated in urban centers.

The directorate general of highways is responsible for overseeing overall planning, programming, and implementation activities of road network development and for ensuring that these activities are kept in line with an established policy. The directorate general has the following objectives:

- Enhance the effectiveness of road network use and increase the efficiency of distribution services;
- Increase the road network's contribution to rational development and create employment opportunities;
- Enhance the effectiveness and efficiency of road management by applying the principles of deconcentration and decentralization; and
- Encourage the participation of the private sector in road investment.

To ensure the achievement of these objectives, major efforts are being made to decentralize financial and management responsibility for road infrastructure development and maintenance. Regional governments will take over these responsibilities through a coordinated management mechanism, as reflected in the budget structure and institutional arrangement in Figures 1 and 2 that the Interurban Road Management System (IRMS) is targeted to serve.

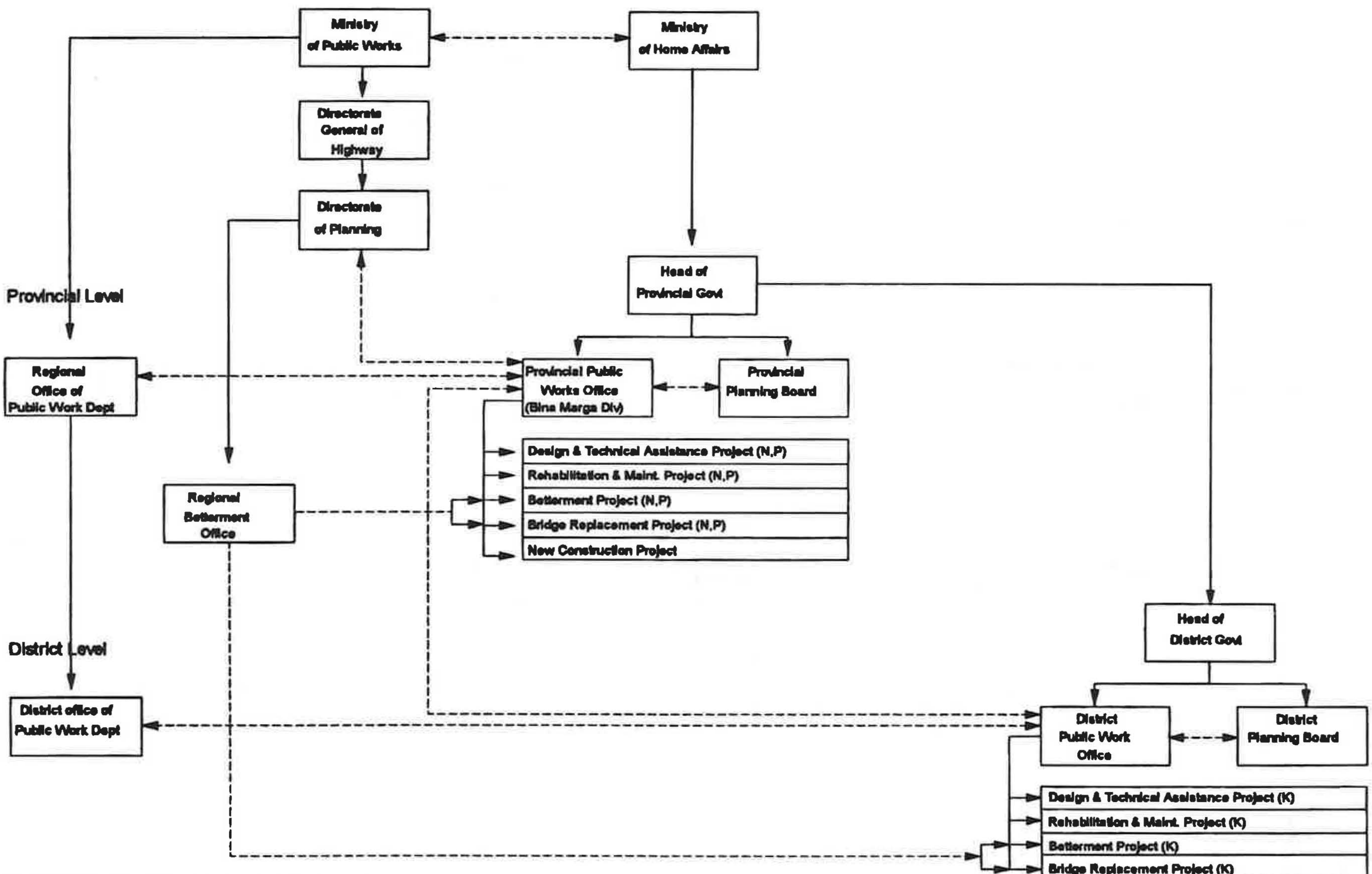
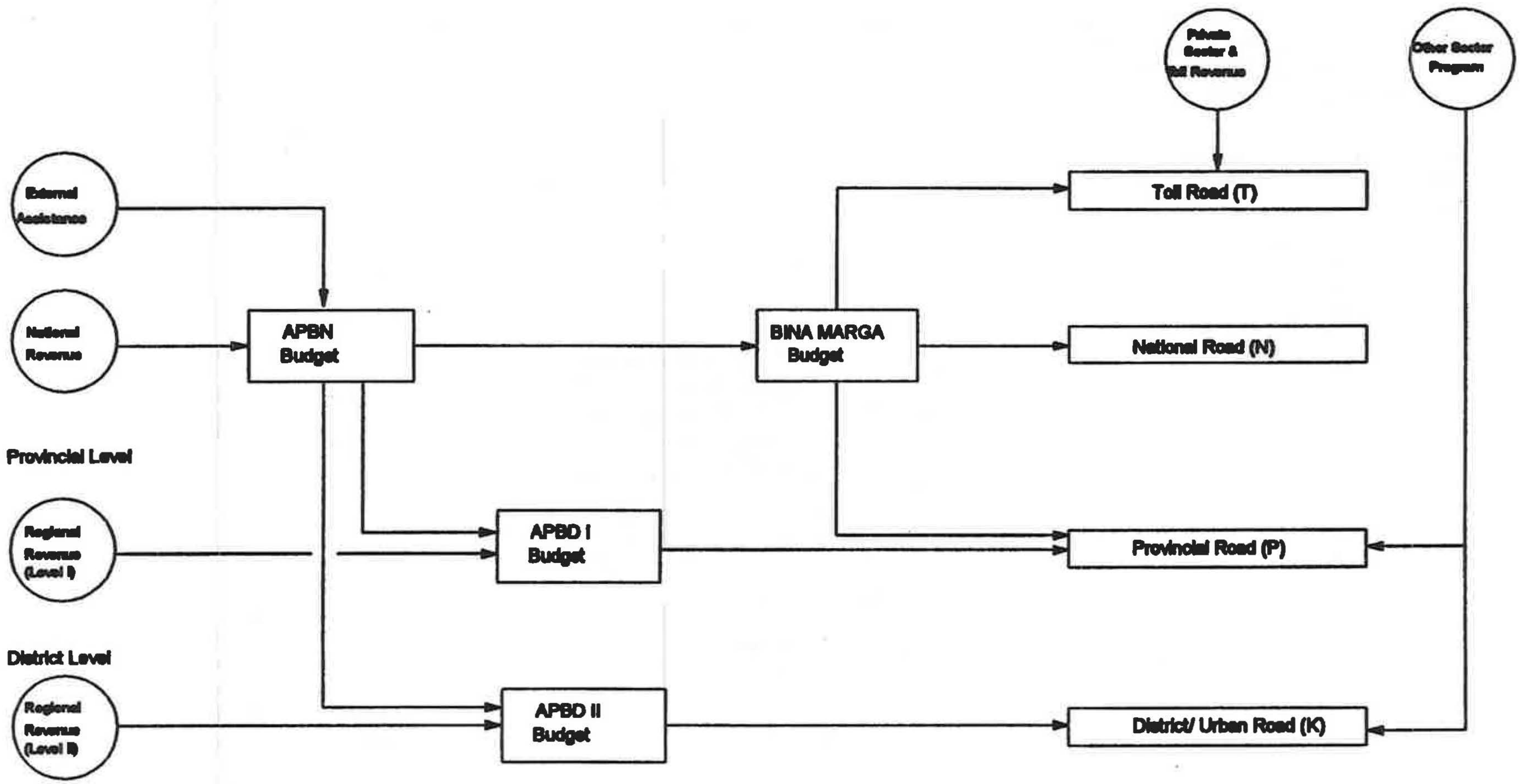


FIGURE 1 Road development institutional arrangement.



Legend :
APBN : National Budget
APBD I : Provincial Govt Budget
APBD II : District Govt Budget
BINA MARGA BUDGET : Directorate General of Highway Budget
○ : Source of Budget

FIGURE 2 Budget structure of road development.

From 1987 to 1989 IRMS was developed on a microcomputer-based local area network, followed by the development of a bridge management system (BMS), an urban road management system (URMS), a toll road management system (TRMS), a local road management system (LRMS), and other monitoring systems aimed at improving the management of all roadways in Indonesia.

Since the introduction of IRMS, additional efforts have been made to enhance the performance of existing systems. These efforts include the introduction of graphic interaction features to IRMS, a study of road capacity expansion (improvement on FS methodology), strengthening the FS unit in Bina Marga, and the first stage of development of an integrated road management information system adopting multimedia technology.

These systems have had a major impact on concerned institutions, and the advent of computer technology has provided managers at all levels the means to better respond to the needs of day-to-day operations and long-term planning activities. Implementation of these systems, including development and operation, in the past frequently required greatly extended time schedules and budget; some systems were less functional than originally intended; and opportunities were missed to effectively place appropriate technology in the hands of users. The purpose of this paper is to identify the principal institutional impacts of implementing IRMS and to identify problems and constraints encountered during previous system implementation projects.

IRMS Development and Implementation

System Development

Many management systems have been introduced during the past 12 years to improve the performance of the planning, programming, budgeting, design, and implementation monitoring functions of Bina Marga. This has resulted in the present system, IRMS. Earlier systems included the following:

- GENMERRI, which focused mainly on a few rehabilitation and reconstruction projects;
- The Road Maintenance Management System, which focused on supporting provincial-level routine and periodic maintenance efforts and on assisting TPU with planning and programming at the national level; and
- The Road Design System, which focused on the design and preparation of contract documents for rehabilitation projects and which was able to cope with more than 100 projects annually.

Between 1987 and 1989 IRMS was developed on the basis of HDM-III, the highway design and maintenance model from the World Bank. This was followed by the development of BMS, TRMS, LRMS, and other monitoring systems aimed at improving the efficiency of roadway management in Indonesia. All these systems are microcomputer-based and are linked by a local area network.

IRMS Structure

IRMS comprises a central data base and five application modules, each of which relates to a distinct phase in the process of project preparation and implementation and to the institutional responsibility of that phase. These modules are planning, programming, road design, economic review, and budgeting. A sixth module, Construction Implementation, is nearly completed.

To accommodate the desire for increased decentralization, all modules are designed for operation by central and provincial users. Two or more application modules may draw on the same data item in the central data base, ensuring consistency of results at the planning, programming, design, and budgeting stages.

Each module produces output as printed reports and data-base files. The outputs, therefore, may be used as management tools in their own right or by other modules for further development.

IRMS Implementation

In its early form, IRMS was used to develop 3- and 5-year expenditure plans during the Repelita V (fifth 5-year development plan) period and to assist in the determination of 1989–1991 multiyear contract packages. Some revisions to the system have since been made in light of this experience.

To ensure success, many training sessions were held at the central and provincial levels and included senior management, highway officials, engineers, and operational staff. Technical assistance was extended to the provincial level through consultant support to assist in data collection, data entry and audit, and local use of the system in the program and budget preparation phase.

Some of the main problems experienced during initial implementation follow:

- The poor quality of data on traffic, pavement roughness, pavement condition, and the position of ongoing projects.
- Divided responsibility for the programming of provincial roads. This is theoretically the responsibility of each province, but the mechanism is complicated by the fact that most funds needed for these roads come from loans handled centrally, in which the lending agencies impose certain conditions on the projects they finance.
- The lack of understanding of sound planning and programming principles at the provincial level.

The following institutional impacts resulted from IRMS:

- The preparation of expenditure plans has become faster and more comprehensive, and these plans are more widely used.
- The directorate general of highways introduced graphic interaction through the commission of local consultants to simplify the learning and training process to ensure that local use of the system will be enhanced.
- Technology transfer gained during system development has enabled local consultants to participate in system enhancement.
- The directorate general of highways has pushed to extend IRMS to interface with BMS, TRMS, URMS, and LRMS, moving toward a comprehensive system that will combine all systems developed for the individual networks and provide a general expenditure planning module that links each major subsystem into a total road system.

Regardless of these problems, there is a growing acceptance of the system by the central directorate general of highways and at the provincial and parliamentary levels for Repelita VI preparation and discussion, as indicated by the increase in demand for program data generated by the system.

Problems and Constraints

Obstacles encountered during IRMS implementation can be categorized into three major groups as outlined in the following discussion.

Organizational and Institutional Factors

Factors relating to organizational and institutional issues were identified as major contributors to ensuring successful implementation of IRMS. The obstacles frequently encountered during system implementation that can be attributed to institutional issues include the following:

- Lack of planning and management support;
- Lack of commitment from the management of all organizational units involved because of the failure to identify common goals and potential benefits to each party;
- Inadequate high-level management support partly due to a lack of understanding of the potential benefits of the system and an unrealistic view of the time and resources required to implement it;
- Lack of a comprehensive implementation plan that is flexible enough to respond to internal and external changes and to describe the steps of implementation, milestones, and the responsibilities of those involved;
- Inadequate intra- and interdirectorate coordination and communication at all levels; and
- Apathy and fear of change.

These obstacles have contributed to the lack of enthusiasm to promote information exchange among the directorates and subdirectorates within Bina Marga. An illustration of this is the lack of accurate and up-to-date physical and financial information for ongoing projects.

In essence the strict hierarchical structures of organizations limit communication and inhibit the sharing of resources, which is important in maximizing the benefit offered by implementing information technology.

Issues relating to staffing availability and training include the following:

- There is a scarcity of trained staff for planning, management, and system operation.
- Organizations often are too ready to accept the claims of user-friendliness of the proposed systems and do not plan for familiarizing and training users.
- The training programs were not adequate or sufficiently directed to users' application environments to bring them to an operational status quickly.
- Insufficient attention was given to organizational culture and the cognitive styles of users.
- Benefits were not quantified well enough to justify the allocation of needed funds.
- There was insufficient funding for system development and refinement and for sustaining the operation of the system.

Standards and Data Integration

More users are now realizing that the existence of standards and improved data integration are fundamental in system implementation and operation. Typical problems encountered include the following:

- Insufficient design and development of organizationwide data dictionaries that cater the needs of users at all levels;
- Lack of standardization in data structure and format, which inhibits the transfer, exchange, and integration of data;
- Scarcity of acceptable guidelines and standards for data sources to establish consistent accuracy standards, coding schemes, and interrelationships of data; and
- Insufficient organizationwide procedures for updating the data bases, particularly from regional Bina Marga offices.

These factors have compounded the difficulty in promoting automation of information exchange among the directorates and subdirectorates within Bina Marga, with particular reference to exchange of information between IRMS, BMS, LRMS, and URMS.

Technical Factors

Technical obstacles to system implementation and operation were actually found to be minor compared with the other two groups of obstacles. This does not mean that users are not experiencing problems with their hardware and software. It simply indicates that the technology is available to better serve users' needs and that the technology is improving rapidly. Some of the frequently encountered problems follow:

- Software and hardware are not suited to the targeted application.
- Software too complex to use has been created in LRMS and URMS.
- The use of proprietary software has hindered the efforts to share data and processing resources.
- Technology is immature and volatile.

Conclusion

Although technological advances continue to meet the demands of users, the major obstacles to successful IRMS implementation are institutional in nature. In the end, it comes down to people: high-level management with long-term vision; mid-level management with the talent and dedication to direct system development and operation; and the users who must apply the technology to real problems. Furthermore, the demand to establish an open environment that will allow data sharing and integration across platforms and systems needs special consideration because data sharing cannot reasonably be implemented by requiring all users to operate a single system.

WORKSHOP SESSION 9

Defining an Appropriate System

Brian R. McWaters (Leader), *Iowa Department of Transportation*

The Workshop on Appropriate Systems addressed the selection, development, and maintenance/operation of a pavement management system. Each of the session's 37 participants from around the world was assigned to one of four groups. Each group had a specific topic: system selection, system development, or system maintenance/operation. Each group was instructed to identify important factors in its assigned area and to establish priorities for these factors.

Arthur Taute, from South Africa, presented the important factors identified by the first system selection group:

1. Agency goals
2. Network size
3. Funding mechanisms
   a. Organization type
   b. Central/decentralized control
   c. Requirements of funding organizations
   d. Adequate justification for system
   e. Method of allocation
4. Agency skills to maintain system
   a. System cannot be a black box from consultants, with no documentation
   b. System should be no more complex than what can be managed
5. Flexibility and transparency/accessibility
6. Costs
   a. Implement system in successive steps
   b. Ensure credibility and keep costs under control
   c. Start simple with reasonable costs
7. Integration with other systems
   a. Integrate system with other systems, including traffic data systems
   b. Ensure that all data are compatible and accessible

Jim Delton, from Arizona, discussed the factors identified by the second system selection group:

- Consistency across the organization to preserve what it has and to enable it to improve in the future
- Decisions about agency goals and objectives—What does pavement management want so that objectives can be met?
- Level of sophistication/flexibility
- Historical data—If agencies do not have historical data, how do they get started?
- Conflicts with overlapping infrastructure
- Establishment of priorities—Determining competition for funding and evaluating other infrastructure needs and basic human needs to establish priorities for pavement projects
- Agency skills
- Preserving what the organization has and ensuring that the new system is compatible with existing systems

Erlan Luckanan, from Braun Intertec, addressed factors selected by the third group, which was concerned with system development:

- Compatibility with existing systems
- Human factors
- Harmonization, particularly in data sets, types, and definitions
- Needs (driving forces)
- A democratic, central system for decision making—Policies for use of artificial intelligence and surface condition data to set priorities

Omar Smadi, of Iowa State University, presented the factors selected by the fourth group, which dealt with system maintenance/operation:

- Flexibility to accommodate changes in technology and data collection
- Reliability to improve credibility
- Capability to review and update the system
- Necessary resources within the organization—How the system will be handled, including assessing needs and determining responsibility for decisions
- Appropriate skill levels within the organization
- Ability to assess training/education needs and costs
- Compatibility within the organization to help other groups maintain coordination with the organization

In addition, the group noted that pavement management is an ongoing, dynamic process that must be continually reviewed.

After group presentations, the workshop concluded with a discussion that addressed other issues:

1. It is important to get early involvement of people from all parts of the agency and to perform marketing to establish "ownership" by as many people as possible.
    a. Do not undervalue the power of politicians.
    b. Pitch to the politicians gradually, and describe what is intended in lay terms.
    c. Select a champion to take the agency forward.
    d. Pick appropriate times to respond to management needs, and answer all questions, leaving nothing dangling.
    e. Use the public, an excellent resource that can help build consensus, when necessary.
    f. Get management support, and find a sponsor who will support the activity.

2. We need to concentrate more on people than on machines. Education and training are important, particularly for administrators and managers, to help them keep up their involvement in and enthusiasm for the process.

3. Many organizations do not have continuity because of having only one person in charge. System development—whether done in-house or by consultants—based on time, need, and personnel resources must be thought out to ensure a long-term, effective system.

4. When a company uses consultants, the contract must be managed carefully to ensure accuracy and completeness.

5. It is a good idea to conduct a pilot project on a smaller scale to ensure that time and resources are not wasted on a larger scale.

WORKSHOP SESSION 10

User Versus Agency Costs

Per Ullidtz (Coleader), *Technical University of Denmark*
Ram B. Kulkarni (Coleader), *Woodward-Clyde Consultants*

This workshop was presented as a court case. First, two different opinions were stated by the workshop coleaders: (*a*) user costs should be quantified in monetary value, even if they involve a number of political decisions, and (*b*) because uncertainties are too large and can lead to improper decisions, rather than quantifying user costs in monetary value, the impact on users should be considered, using more stable parameters.

The audience was formed into juries, each electing a spokesperson, each jury was asked to give a verdict for or against quantifying user costs in monetary terms. If consensus could not be reached, the juries were asked to cast a vote. In addition, they were asked to jot down their main arguments and present them to the other juries during the last part of the workshop.

Summary of Jury Questions

Most juries found it impossible to pronounce a straightforward verdict on user costs versus agency costs. Almost all juries found it necessary to distinguish between network level and project level, although there was no consensus on how these levels should be treated. Some juries added a third level, strategic.

There appeared to be agreement that user costs are a valuable tool for planning, policy making, and setting priorities at the network and strategic levels. On the project level, the juries questioned this belief.

One concern was that user costs tend to overwhelm agency costs, resulting in much too expensive, unrealistic levels of maintenance if total costs (i.e., user plus agency costs) are to be minimized. In addition, benefits often are so substantial that nobody believes they exist; therefore, to avoid overselling the case it can be advantageous to use other measures of user impact. On the other hand, one jury believed that user costs can be properly used to support requests to cover funding shortfalls.

Most juries saw a need to distinguish between the "hard" agency dollars and the less tangible user benefits. The need to better data on user costs, even to aggressively pursue information, was expressed by all juries. For example, the juries market believed that research on user expectations can provide valuable information to decision makers.

One jury believed that the reduction in user costs should be considered a benefit to be analyzed in benefit/cost evaluation. The benefit/cost evaluation was considered different from life-cycle cost analysis, in which all costs (to agency and users) are combined.

In general it was believed that the delay costs caused by construction and maintenance activities can be quantified in monetary terms. Quantifying safety costs and vehicle operating costs was considered difficult but still possible. Several juries found that trying to quantify environmental costs can be a waste of time.

One jury considered it necessary to develop different user cost models, depending on whether the models were to be used in developing or industrialized countries, in urban or rural areas, or for comparison within sectors (transport) or across sectors. Another jury thought that it might be necessary to allocate funds to rural and urban areas, a priori, before any benefits and costs are considered. On the other hand, the need to find common criteria or measures that can be used for several modes of transport (e.g., within the Intermodal Surface Transportation Efficiency Act) also was expressed.

Only one jury voted squarely for the inclusion of user costs. User costs are part of life-cycle costs, and although some impacts may be difficult to quantify, this should still be tried using the best available information, assistance from economists, and sensitivity analysis. Combining different user costs was not seen as a case of adding apples and oranges. This, however, was believed to be the case when different indices are combined.

Conclusion

There was a great deal of willingness at this workshop to include user costs in decision making, but current user cost models were considered unrealistic or incomplete.

WORKSHOP SESSION 13

Institutional Issues Affecting Pavement Management and Use, and Methods To Overcome or Bypass Them

Tung S. Dong (Leader), *International Road Federation*
Bryan E. Stampley (Recorder), *Texas Department of Transportation*

Two workshop sessions, 13 and 24, were devoted to institutional issues affecting pavement management system (PMS) implementation. The purpose of the sessions was to get those involved in pavement management to help identify methods to overcome institutional and people barriers to PMS implementation and use.

Institutional issues were divided into three types:

1. People issues and barriers (4 issues);
2. Organizational issues and barriers (11 issues); and
3. System design, development, and selection (3 issues).

Session 13 addressed 11 of these 18 issues. The Session 24 summary addresses the other institutional issues.

People Issues and Barriers

These problems are related to the personalities and interpersonal relationships of people within an organization.

Turf Protection

Turf protection occurs when people resist PMS implementation to prevent a perceived loss of power. Turf protection, quite simply, is a fight based on fear. As the name suggests, it is a fight to protect territory. More important, it is a fight to protect a person's sense of importance. Turf protection is only a sign of some other institutional issue—whether it is fear of exposure, "not invented here," resistance to change, or some other issue. The important thing is to treat the underlying cause of turf protection and not waste time fighting the turf protection itself.

Adults work to earn a living, but they also work to create a sense of competence—that is, the ability to do something well. This sense of competence can even become an identity. Thus, adults often describe themselves in terms of their work; for example, "I am an engineer," or "I am a doctor." When competence is linked closely to identity, anything that threatens that competence may be perceived as an assault on the person's identity and sense of worth.

All this may seem unrelated to pavement management, but it does explain some of the intense turf battles that PMS implementation has created. In fact, some of an agency's most highly skilled and valuable people can be the most vicious turf warriors.

It has become popular for agency decision makers to publicly chastise turf warriors. Such people are accused of being resistant to change. The implication is that their opinions are worthless and that their value, and even their future, is limited. Such public chastising only entrenches turf warriors and strengthens their sense of isolation.

PMS personnel should recognize what is of value in the turf warriors' threats and devise ways to take advantage of the ability to contribute that the turf warrior is fighting so hard to preserve.

Successful Solutions

A common theme in many "successful" solutions is to involve—not isolate—the turf warriors. Persons who initially feel threatened by a PMS can become some of its strongest supporters.

Metropolitan districts in the San Francisco Bay Area have been requesting PMS information from the Metropolitan Transportation Commission (MTC) to support their requests for funding. MTC has been willing and able to provide PMS information to these districts. But, more important, MTC has helped the districts benefit from the new information.

Cape Town, South Africa, takes a centralized approach to planning its road resurfacing program. Resurfacing needs for the entire area can be considered. Its PMS produces graphs that provide resurfacing information to decision makers and politicians. A bus tour was also arranged to demonstrate to politicians how resurfacing decisions were made. The tour apparently was successful—the next year's resurfacing budget increased by 20 percent.

The PMS staff in Texas has been distributing PMS information to the state's decentralized and highly autonomous district offices. District users are now asking for more ways to use this new information in their road resurfacing and rehabilitation work.

Unsuccessful Solutions

Session participants did not identify any unsuccessful solutions, although it was obvious from the discussion that they had had many such experiences.

Untried Solutions

One untried solution is to give district offices raw PMS data and let them use them as they see fit. Closely related to this is to put local PMS data on microcomputers (or personal computers) for use at local offices, for agencies using a centralized mainframe computer for their PMSs.

Fear of Exposure

People often resist PMS implementation because they fear that the PMS will show that previous decisions were incorrect or less accurate than previously thought. Fear of exposure is the nastiest of the four people issues and barriers. It is also the most common, and it masquerades as turf protection, "not invented here," or resistance to change.

As the phrase suggests, fear of exposure is based on fear—nothing more, nothing less. A person is afraid that the PMS will undermine his or her position. The PMS might show that previous decisions were wrong or that his or her opinions were not quite so sound. In addition, the PMS might show that this person could have been doing a better job all along.

What makes fear of exposure so nasty is that it thrives in an atmosphere of distrust, which is what seems to be happening in many agencies. Employees distrust management for withholding information; management distrusts employees for withholding information; decision makers distrust politicians and their motives; politicians distrust decision makers and their abilities; and the public distrusts everybody. With all this distrust, no one feels safe, and certainly no one feels that he can make a mistake. But that is exactly what the PMS seems to be saying—that someone made a mistake.

PMS staff can do nothing about fear of exposure. Only agency decision makers can create an atmosphere of trust that assures an employee that his or her position is secure. Of course, the decision makers themselves must work in an atmosphere of trust.

When an agency creates an atmosphere of trust, distrust fades. When distrust fades, it takes away the fear. And when the fear goes away, the fear of exposure goes away.

Successful Solutions

Fear of exposure increases when a person feels isolated from the PMS effort. One way of eliminating this isolation is to involve such people in the development and implementation effort. Another way is for PMS staff members to visit such people and say, "Can I help you with . . . ?" or "Let me help you with . . . ." This way, the PMS staff helps users solve problems for themselves. By making the user's job easier, the PMS staff makes its job easier.

Still another way is for the PMS staff to work with key users to help them discover their needs. The staff then fits the PMS to meet those needs. Related to this idea, especially when working with local field users, is the approach of trying a few small changes, instead of many large ones; for example, adding one or two new reports to an existing PMS and letting local users review them.

Equally important, as proven in the state of Utah, is the idea of the PMS staff providing long-term, continuing training and education. The distinction between training and education is important. "Training" refers to basic PMS instruction; for example, "How do I run this report?" "Education" refers to detailed instruction in PMS concepts and usage; for example, "What does this value mean?" or "How does this optimization program work?" The PMS staff must be ready to provide both, periodically, over a long period of time.

In these examples, session participants clearly indicated that agency decision makers should be included in these efforts. Only in this way can the PMS staff help the agency create the atmosphere of trust needed to eliminate fear of exposure.

Unsuccessful Solutions

Although there were certainly many unsuccessful solutions to discuss, session participants quickly put the mandated PMS at the top of their unsuccessful list. Of course, many agencies have mandated their PMSs. And, as will be discussed later, PMS mandates do have their advantages.

Untried Solutions

There was much discussion of total quality management as applied to PMSs, but session participants admitted that they had not yet applied these concepts to PMSs.

Resistance to Change

Resistance to change is the observation that some people simply do not want to change. As with turf protection, the most vocal opponents often are the most valuable allies. A person will ask, "Why should I change what I am doing?" or "What's wrong with the way I am doing things?" Sometimes there is no good answer to these questions, in which case PMS personnel should be quick to admit that there really is no reason to change. PMS staff should be careful not to peddle change for the sake of change—the emphasis should always be on improvement. After all, anyone can change things.

Improvement really is the key to this issue. In fact, the issue is termed resistance to change because few people actively resist improvement. Thus, it is important to direct PMS efforts toward making work easier and more effective. When that happens, people will feel better about their positions in the organization. They will also see the PMS as a tool to help improve their work, not as a tool to merely change their work.

In the discussion, it was mentioned that age is an important factor. The young person seems to demand change, the middle-aged person seems to accept change, and the older person seems to resist change. This does not mean that all older people resist change; it just means that they are more likely to resist change. Given the proper circumstances, a person of any age will resist change.

Gaps in hiring can create blocks of younger and older people within an agency. They can even create a generation gap between the typically young staff members and the typically older decision makers. In the United States, a hiring gap was created by the push to build the Interstate highway system in the 1950s and 1960s. In South Africa, changing economic cycles created a hiring gap.

Session participants believed that PMSs might become more acceptable in the future, simply due to changes in agency personnel. However, they also identified ways to speed the process.

Successful Solutions

Communication is the key to overcoming resistance to change in an agency. The PMS staff should take the time to involve decision makers and users. Formal communication, such as committees, working groups, and newsletters, is important, but staff members also should take advantage of informal communication. Sometimes a simple office visit or a phone call can break down resistance and turn PMS implementation into a more friendly, human effort. When people are feeling threatened by change, they often just want to have their concerns heard, understood, and considered. Fear is the basis of PMS resistance in many cases. Anything that the PMS staff can do to reduce fear will speed PMS implementation.

When dealing with decision makers, session participants found it important to show that the PMS process is rational. Decision makers are under great pressure to justify their decisions. Many of these decision makers do not like having to justify their decisions to others—often they are engineers who, by virtue of their education, expect to be trusted. However, decision makers feel more comfortable when defending a rational process. When the PMS staff makes the decision maker's job easier and more effective, the staff makes its job easier and more effective.

Another helpful method is to show the benefits of PMS usage. For example, Australia's PMS must define the value of the highway network. Benefits then can easily be shown in terms of value gained or lost. A person will often resist change by saying something such as "This new way had better be good!" Showing the benefits of PMS usage will help such a person see that the new way is good.

Unsuccessful Solutions

Session participants agreed that one of the quickest ways to cement resistance and kill a PMS effort is to send down an edict from above requiring PMS usage. As will be discussed later, this finding is especially interesting to agencies in the United States working to meet the requirements of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA).

Untried Solutions

Session participants did not identify any untried solutions.

Organizational Issues and Barriers

Size

Agency size (number of people or geographic area) can affect PMS implementation. Agency staff must be trained in the effective use of the PMS and must be educated in the purpose of the PMS. Larger agencies require more effort in training and education because there are more people involved, or people are scattered across a large geographic area, which can slow implementation. However, the large agency usually can hire PMS specialists to help with training and education. The problem in the large agency is that there are more informal leaders who can undermine PMS usage. Smaller agencies do not have these problems. Smaller agencies can train and educate their users quickly; however, they rarely have the specialized staff available to do so. A more serious problem in the small agency is that it can be almost impossible to bypass a single person who resists PMS implementation.

There is no optimum size for an agency wanting to implement a PMS. The large agency can hire a more technically trained staff, but that staff must overcome the agency's greater inertia. The PMS staff must be respected highly by all levels of the organization, especially the top, if it is to overcome inertia and develop its own momentum. Even then, it is very difficult for staff members to cross the organization's boundaries (as will be discussed later). It is also often difficult for a large agency to adapt rapidly to changing conditions. Thus, the large agency may envy the responsiveness and simplicity of the smaller agency.

But the smaller agency is often constrained by a lack of resources. It can often move more rapidly but may have few technically trained employees to solve a problem. Thus, the smaller agency's ultimate effectiveness may be just as limited.

Geographic size is also important. A decentralized agency covering 80 000 to 100 000 km^2 will have completely different needs than a centralized agency covering only a few thousand square kilometers. If PMS users are relatively few but scattered over a large area, the agency must be willing to finance the extended travel time necessary for personal support. An agency in a more densely populated area—a large number of PMS users in a small area—will have to plan more frequent training sessions to keep class sizes at a manageable level.

In the end, the issue of size relates to the number of people and their distribution throughout a geographic area, not necessarily to the size of the PMS staff.

Successful Solutions

At a large agency, the PMS staff should form a steering committee made up of all sections involved in pavement management. High-level people should be included to provide a sense of direction and to ensure that the PMS will fit smoothly into the agency's overall operation.

At a smaller agency, if one person is blocking PMS implementation, the PMS leader can try to (*a*) persuade that person to support the PMS or (*b*) persuade that person's superior to support the PMS. Peer pressure can help persuade a person to support the PMS, but it can also be perceived as a sneak attack and increase the person's resistance. Once again, the PMS leader must overcome one or more people issues and barriers when trying to gain the support of a reluctant person.

Session participants described the benefits of using consultants at large and small agencies. Although consultants often are dismissed as being high priced, many agencies find that the expertise obtained is well worth the money spent. Some agencies use consultants as their full-time PMS staff, and other agencies use consultants to provide specialized technical support. In all cases, agencies must retain control of consultants and their contracts. If an agency is unable or unwilling to retain control, it should look elsewhere for support.

Unsuccessful Solutions

Several participants described the problems caused by using part-time staff for PMS development. The consensus was that the PMS staff and especially the PMS leader, or PMS engineer, must work full time. Otherwise, they will spend so much time "putting out fires" that they might forget how to use the PMS.

Untried Solutions

Session participants did not identify any untried solutions.

Structure

"Structure" refers to the need for pavement management decisions to cross organizational boundaries. Some organizations encourage communication among various central office departments and regional or field groups. Other organizations require that communications go up the chain of command before crossing to another area of responsibility. The lack of effective direct communication among PMS users can seriously threaten the implementation and effective use of a PMS.

Structure often works as a barrier to communication. Organizations that encourage communication between work groups are thought of as free flowing, adaptive, responsive, or some other positive term. Decision makers in such an organization must be able to completely trust their employees to give them so much freedom. The organization works well if employees keep decision makers apprised of latest developments and if the decision makers can keep up with it all. The problem is exactly that—how to keep up with it all.

Structure helps an organization keep everybody on the same path, much like a conductor keeps all orchestra musicians at the same place on the score. An organization's structure is not necessarily bad. But when it begins to block the flow of information between work groups, it becomes an institutional issue.

Successful Solutions

As with other institutional issues, communication is the key to working with and through an organization's structure. However, communication is exactly what structure tends to block.

A committee that includes all sections involved in pavement management can help PMS staff to deal with organizational structure. Another solution is to place the PMS staff function high enough in the organization to (*a*) command the respect of persons at all levels of the organization and (*b*) easily and effectively cross organizational boundaries.

Unsuccessful Solutions

Some PMS staff members retreat from the organization's structure and try to develop the PMS in a vacuum. Session participants agreed that this does not work. Again, communication is vital to PMS development and implementation.

Other agencies place their PMS staffs too low in the organization. These staffs are not allowed to easily and effectively cross organizational boundaries. Even if they could, they do not command enough respect to be successful. In such situations, some PMS staff members get discouraged and retreat from the organization's structure. Other PMS staff members try more drastic methods of making the PMS visible, which, unfortunately, increases resistance to change. Other PMS staff members simply lower their expectations. In any event, the result is the same.

Untried Solutions

Session participants did not identify any untried solutions.

Stability

Stability describes how often the agency's basic organizational structure changes over time. A more stable structure allows the use of a more complex decision support system.

Stability is closely related to the issues of size and structure. But it must also be related to the organization's sense of rigidity and mobility.

The authors define stability in terms of how often the organization's basic sense of purpose changes. This definition is closer to that used when describing people as stable or unstable. And it completely divorces stability from size. After all, few things are more ridiculous than a large agency trying to prove that it is as nimble as its smaller counterparts—unless it is a small agency trying to prove that it is as rigidly stable as the most stolid large agency.

State highway agencies have seen their entire sense of purpose turned upside down with the passage of ISTEA. Large agencies, such as the Texas Department of Transportation, completely reorganized in the space of 4 months. And whereas the outer organization appears to have restabilized, the inner sense of purpose, which affects PMS implementation, is still up for grabs.

An agency may never change its organizational structure, but if its inner sense of purpose is always changing, it will be next to impossible for a PMS to support the agency's goals. Another agency may always be reorganizing to adapt to changing conditions, but if the agency's inner sense of purpose is stable, it will be easy for a PMS to support the agency throughout its reorganizations.

Successful Solutions

Session participants addressed stability in terms of PMS personnel, availability of PMS information, and data collection. Stability of PMS personnel has not been achieved (as described in the One-Person Show issue in the Session 24 summary). It will be covered in the section on untried solutions.

As far as the stability of PMS information, one successful approach has been to load PMS information and reports into the agency's central mainframe computer for access by all levels of the organization. Thus, staff members get to see the same information that management sees. This helps them address problems before they become serious enough to warrant management review. Agencies using microcomputer-based PMSs can do the same thing. Well-documented PMS user manuals also have helped PMS users and PMS staffs learn their systems.

As for the stability of PMS data collection, several agencies have found that consultants can be helpful, especially if their contracts cover all roads or if their contracts cover more than 1 year.

Unsuccessful Solutions

Closely related to the idea of using consultants to collect PMS data is a problem with using part-time employees to collect pavement rating data. Although many agencies' pavement raters are experienced, it has been difficult for these agencies to continually train and keep pavement raters.

Untried Solutions

Session participants mentioned the problem of keeping qualified PMS staff members. (This issue will be covered in the Session 24 summary as well.) As soon as qualified employees become valuable to an agency, they transfer or are promoted. One untried solution mentioned was for agencies to develop a dual career path so that technical staff members can be promoted to higher pay levels without having to become managers. Another untried solution was simply to place PMS staff members at a high enough position and pay level so that they have a reason to stay.

Resources

A PMS cannot be developed, implemented, or effectively used if resources are not available. This includes resources for those responsible for the PMS and the funds needed to implement the programs developed through the effective use of the PMS.

Resources are not just money—they are also personnel and, in the case of data collection, equipment. This issue is really two issues.

First is the issue of providing resources for those responsible for the PMS. A PMS is a high-dollar and, in some cases, a high-risk investment. Many agencies have been reluctant to take the plunge. In the United States, ISTEA has fairly well decided that issue—it is no longer a question of if or when, but how. The resources issue still remains. The fanciest PMS is useless if there is no one to distribute the information, answer questions, or improve the system. The most sophisticated fleet of data collection equipment is useless if there are not enough operators to collect the data, and the largest staff of operators is useless if the equipment is missing, in disrepair, or obsolete.

Second, and often more difficult, is the issue of providing funds for implementing programs developed through the effective use of a PMS. Although many good PMSs have the ability to account for limited funding, the fact remains that the funding must eventually be provided. For example, if a carefully designed and implemented PMS comes up with a $100 million resurfacing program, a later reduction to $80 million will not give all the benefits that the PMS, or the program, was meant to provide. The agency may later claim that the PMS was at fault for overestimating the resurfacing program, but that claim can no longer be validated. After all, if the observed results are different from the PMS-expected results, perhaps the reduced funding, and not the PMS, was responsible.

Successful Solutions

One of the best ways to get resources is to find a respected decision maker who will sponsor the PMS effort. The sponsor can campaign for the PMS at the highest levels and maybe even remove many institutional barriers along the way. The PMS staff can help the sponsor by giving examples of other agencies that have used PMSs to solve similar problems. The ability to show beneficial results early also will help the sponsor sell the new PMS to other decision makers and throughout the agency. Once again, PMSs can be beneficial—but people must use them.

A mandated PMS is one sure way to gain resources for PMS development and implementation. Of course, the PMS staff must be prepared to dissolve the resentment and resistance that such a heavy-handed approach can create. Nevertheless, PMS mandates have prodded some agencies that never would have moved on their own.

A lighter, more effective approach is to conduct introductory workshops for top management and decision makers. These workshops give upper-level executives the chance to modify the new PMS to make their jobs easier. The workshops also can give technically oriented PMS staff members an appreciation of the needs of executives. Both can work together to make each other's jobs easier and more effective.

PMS staff can use charts, graphs, and maps to help executives strengthen their funding requests. Once again, the staff can make the executive's job easier and more effective. The executive can then make the politician's job easier and more effective.

Other agencies have established PMS user groups to help people better document their funding and resource needs. Users often learn that their worst problems have already been solved by somebody else. In addition, users get to help solve others' problems.

Unsuccessful Solutions

The PMS staff, and even the sponsor, must be careful not to promise too much too soon or too inexpensively. Overselling the PMS can be fatal if decision makers begin to wonder if the PMS will ever deliver on its promises. In addition, an overly high price tag or an overly long "gestation period" can kill the PMS.

Session participants mentioned two other "deadly" promises: (*a*) a PMS will reduce manpower and (*b*) a PMS will save money. In either case, the decision makers, or worse yet, the politicians, will expect to see an equivalent reduction in force or an equivalent return of revenue.

In the early 1980s, the Texas Department of Transportation used a subset of the Rehabilitation and Maintenance System (RAMS), developed by the Texas Transportation Institute. The department discarded RAMS, mainly for lack of a large enough data collection sample size. (In fairness, it must be mentioned that the province of New South Wales in Australia later adapted RAMS to its agency and has had great success with the program ever since.)

Other participants reported that local districts in their agencies have used their own separate systems. This approach has made it very difficult to get overall funding and other resources.

Untried Solutions

Session participants discussed the use of geographic information system (GIS) technology, but they had not really used a GIS to justify funding and other resource requests. This will warrant further watching as more agencies include GIS technology in their PMSs.

Competing Funding Needs

Almost every agency has more funding needs than resources, and there are always many competing funding needs. It seems that nobody has enough funding anymore. But competing funding needs are not just about funding, they are also about needs. And the interplay between funding and needs creates some interesting situations.

Agencies with a developing road network find that they are very important—they may not get enough funding, but they get most of what is available. When their road network is finally built, they suddenly find that they are not quite so important anymore. There are still new roads to be built, but now the agency is expected to keep the roads smooth, wide, safe, aesthetically pleasing, environmentally sensitive, and so on. Some agency personnel nostalgically begin to yearn for "the good ol' days" when their work was considered important and all they had to do was build roads.

In this sense, competing funding needs are similar to stability—they test an agency's inner sense of purpose. Many transportation agencies publish a written roles and missions statement. These words are helpful, but funding is the reality, especially now when there is not enough to go around. The agency will spend its limited funding on its most important areas.

Successful Solutions

The most successful approach is to present a logical plan that shows that good roads cost less. A PMS can certainly support such plans, which have proven effective when dealing with agency decision makers and politicians. The key is to show that a small investment in pavements now is actually a savings and not a cost, because the investment will save money that will need to be spent later on heavier treatments.

Another approach is to identify specific projects that can be added if funds are increased. In a similar way, the PMS staff or the agency decision makers can identify specific projects that will have to be dropped if funding is cut.

Unsuccessful Solutions

A PMS can be used to show that "if you don't give us the funding we request, the roads will fall apart." Although this approach might work within an agency, politicians tend to view it as a threat.

In addition, an agency should not tell a politician how to raise the requested funding. This is the politician's job, and he or she may value it as much as the agency decision maker values his or her job.

It also is not enough to simply request funding. The agency or the PMS staff must have sound documentation to justify the request.

Untried Solutions

Session participants discussed the idea of an agency going on strike by not repairing roads for a short time, but they agreed that such an approach is very risky. Another untried solution is to increase load restrictions on roads that are awaiting structural rehabilitation. Still another is to transfer some road mileage to another jurisdiction.

System Design, Development, and Selection

Matching Agency Needs

Some agencies have selected and implemented a PMS to justify budget requests, only to find that the system only helps select sections that need maintenance and rehabilitation. Other agencies have tried to evaluate PMS recommendations for their final work programs but found that the PMS sections, costs, and treatments did not match their management process.

Matching agency needs is not just an issue of common sense—it insists that the PMS be usable. By its very nature, a PMS can support and strengthen an agency's existing decision-making process. But it can also challenge that process. Such a challenge creates resistance, as evidenced by the large number of institutional issues described in this paper.

One way to overcome an agency's resistance is to support its existing decision-making process. This has two advantages: (*a*) the agency can learn to view the PMS as a helpful tool instead of as a destructive threat and (*b*) the PMS will have a few years to mature without having to carry the full load of the agency's decision-making process.

The PMS staff must learn as much as it can about how the agency makes decisions. It will then be able to develop a PMS that is usable, instead of just technically sophisticated. Reluctant users will need some encouragement at first, and the best way to do that is for the PMS to meet their immediate needs and be tolerant and forgiving.

Successful Solutions

Once again, a steering committee is essential to defining the agency's goals, needs, and expectations. Some participants even mentioned using a dual committee structure, with a high-level committee to set goals and overall direction and a lower-level committee to provide more direct guidance.

Another approach is to develop and implement the PMS on a small subset of the agency's highway system, then expand it to the full system. This approach keeps development effort and problems at a manageable size. It can also speed up final PMS implementation.

For agencies using a private consultant or other third party, a good contract manager is essential. The contract manager must have enough technical skills to ensure that the agency gets a PMS it can use and enough interpersonal skills to resolve the inevitable misunderstandings and problems.

Unsuccessful Solutions

People who are familiar with microcomputers (or personal computers) know how difficult it is to walk into a software store and buy a program that will meet all their needs. And yet many agencies will spend a hundred or a thousand times as much money to purchase a PMS "off the shelf."

For agencies planning to use a consultant or other third party, it is not enough to let the contract and wait for the PMS to magically appear. The agency also must be prepared to provide a capable contract manager, for the protection of the agency and the consultant. A capable contract manager can head off enough costly problems during the course of a typical contract to more than offset his or her salary and benefits.

Untried Solutions

Session participants did not identify any untried solutions.

Complexity

Some PMS products have been so complex or poorly documented that users have not been able to understand them, much less explain how they work to others. When PMS staffs take recommendations to management, they cannot always explain the basis for programming specific streets for rehabilitation or preventive maintenance. Some PMS staffs cannot explain the concepts on which fund requests are made, nor can they always show the impact of alternatives suggested by management.

How does a PMS provide flexibility without complexity? In many respects, complexity is related to stability. As mentioned previously, stable organizations can tolerate a more complex PMS. Of course, the PMS must be able to adapt to those rare times when the stable organization does change.

Complexity is often confused with flexibility. PMS users want a flexible system with plenty of room to grow in, but they do not want to wade through six levels of menus and a 1,000-page manual. They want to be able to get in, get their information, and get out quickly. And they usually want something completely different tomorrow.

At other times, a PMS is like a huge toolbox. Users paw through the toolbox but they never seem to find the tool they are looking for. After a while, they get frustrated and quit.

Complexity is even a problem for PMS staffs. They must know every "in and out" of the PMS but also must be able to condense that detailed knowledge into something management can quickly and effectively use. Thus, the final word in PMS complexity is KISS (Keep It Simple, Stupid).

Successful Solutions

Session participants noted that they have had the problem, "What do we do if the system developer does not stick around to the end?" The best solution is for the agency to go back to the basics and start again if necessary.

South Africa has taken a three-phase approach to the complexity issue:

1. Network level,
2. Project level, and
3. Site investigation.

Unsuccessful Solutions

Session participants agreed that PMS users must be able to interrogate the system to get the information they need and that a complex PMS needs to have a simple front end to guide users through the system.

Untried Solutions

Session participants did not identify any untried solutions.

Black Box PMS

PMS software is considered to be a black box when it provides recommendations but the reasoning behind the recommendations is not known. The black box raises questions of trust, reliability, and defendability. The decision maker looks at the PMS, sees the data going in and the results coming out, and wonders what happened in between. The decision maker may ask the PMS staff, "How can I explain this to the politicians if you can't even explain it to me?"

This uncertainty can create fear and distrust. How can the decision maker be sure that the PMS will give the same answers to the same questions and that it is not just some wild scheme to come up with more pavement funding?

The black box can make field users feel that the PMS staff is keeping them in the dark as a way of reducing disagreement. Field users value their experience and want to contribute to the agency's decision-making process. They are likely to resent and resist any effort to bypass them. The main fear that the black box creates is that no one knows what is going on.

Successful Solutions

The best way to address the problem of the black box is through long-term training and education. Training addresses basic PMS instruction, which is important for new users. But the key to the black box issue is education, which explains how the black box works. When the PMS staff has properly educated all levels of the agency, the black box disappears, and the PMS becomes understandable and worthy of trust.

Another solution is to develop a PMS that allows users to change various system parameters. A field user can then see how the PMS responds to local changes and can learn about the system on his or her terms. The user can even "reality test" the results against local practice and provide valuable suggestions to the PMS staff for future improvements. In this way, the field user becomes an ally of the overall PMS implementation.

Session participants identified an interesting feature of the black box issue: the black box is acceptable if the results seem reasonable and no one asks any questions.

Unsuccessful Solutions

Several agencies have obtained a black box to solve some pressing pavement problems without first understanding the process causing the problems. Such agencies do not know whether the black box solved the actual cause of the problem.

Untried Solutions

One untried approach to the black box problem is to customize the agency's PMS for every user. Although this approach promises the ultimate in flexibility, it also promises problems for PMS staff members trying to figure out how a user got a particular answer.

Summary

It may appear that PMS practitioners spend a lot of time complaining about how many problems they have. But this complaining is often the first step toward a solution. Complaining has paid off in the form of solutions in at least five areas:

1. Set the PMS unit high enough in the agency's organization so that it will command the respect of persons at all levels of the organization and easily and effectively cross organizational boundaries.
2. Take advantage of committees—they can work! When setting up a PMS committee, be sure to define the goals of the committee and the PMS at the start; get representatives of all key players, even those from outside the agency if necessary; and consider using a split policy/technical committee if necessary.
3. When dealing with PMS users, think about trying a few small changes over time instead of many large changes; involving users instead of isolating them; offering help; and promoting long-term training (how to) and education.
4. When dealing with agency decision makers, think about getting a sponsor decision maker to campaign for the PMS, showing similar problems that PMSs have solved in other agencies, demonstrating a logical plan showing that good roads cost less, and starting with small steps that show benefits quickly. Above all, do not oversell the PMS. Do not promise too much too fast.
5. When dealing with politicians, think about demonstrating a logical plan that shows that good roads cost less and identifying specific projects that can be added if funding increases or identifying specific projects that will have to be dropped if funding decreases. Above all, do not threaten politicians by saying, "If you don't give us the funding we request, the roads will fall apart!" and do not tell them how or where to get the funding.

Other Issues

This paper describes 11 different, but interrelated, institutional issues that can block PMS implementation and use. However, the authors would like to raise several other underlying issues.

1. Institutional issues are mainly interpersonal, not technical. However, professional engineers are often in charge of PMS development and implementation. Although some engineers are very personable and quite skilled at working with others, some people become engineers because of their preference for a quieter, more technical job. Is it perhaps time to suggest that professional engineers are not always the best equipped to oversee PMS development and implementation? But how many nonengineers can balance their interpersonal skills with enough technical ability to oversee the entire PMS effort? Also, how many PMS staff members are truly equipped to effectively cope with the conflicts that the PMS effort will bring?
2. PMS practitioners frequently insist that an agency's PMS unit be placed high enough in the organization to command the respect of persons at all levels of the organization and to easily and effectively cross organizational boundaries. This suggests that PMS staff members would like to be placed close to the decision maker. How will the decision maker believe that this is something other than a request for power? After all, any person who values his or her job and opinions would ask for the same position. Why should a decision maker agree to such a request by the PMS staff? What separates PMS practitioners from others in the organization?
3. How does a PMS leader explain the decision-maker's tendency to trust an outside consultant or researcher more than the highly trained PMS staff? Does the PMS leader have any chance of getting the decision maker to place greater trust in the PMS staff?

How does the PMS leader keep the PMS staff from becoming demoralized by this tendency? What motivation does a PMS staff member have to keep up technical skills under such conditions?

4. Agency decision makers are being bombarded by so many requests from so many directions that they seem to become isolated from the rest of the agency. Yet the PMS effort needs the guidance, direction, and support of these decision makers. How can the PMS leader and staff penetrate the isolation at the top for the benefit of the decision makers and the PMS effort?

5. When an agency develops a PMS, it often will "reality test" the PMS against past agency results. For example, the PMS staff will compare the system's list of recommended rehabilitation sections against an experienced employee's list. This approach assumes that the experienced employee's list is more accurate than the PMS's list. When and how does the PMS leader propose that the PMS is more accurate than the agency's past practice? After all, if the PMS is meant to enhance the existing process, why should it be fit back to the results of the old process?

6. Should funding be tied to PMS results? In theory, it should be. But the PMS cannot consider every factor that influences a pavement decision. Still, the PMS does identify pavement needs. Why not tie funding to those needs? One problem with this approach is that the PMS will appear to reward pavement managers who have poor roads by giving them more money, while penalizing managers who have good roads by giving them less money. Yet politicians require greater accountability from their agencies and even suggest that personnel performance ratings be based on such verifiable measures as pavement condition. How can an agency decision maker keep a war from breaking out between pavement managers? How can the decision maker give a manager a good performance rating and then cut the manager's funding to address pavement needs in another area? And how does the PMS leader and staff keep from getting caught in the cross fire between agency decision makers and agency pavement managers? After all, pavement managers and field users are afraid that the PMS will drive funding levels and take away their influence. In such a situation, how can PMS staff ease the fears of pavement managers and field users without misleading them?

7. The most important issue of all is, When will agencies learn to use PMSs for more than just defending tax increases? People around the world have less money available for paying new taxes than ever before. Yet agencies keep using PMSs to justify tax increases. Politicians and even the public are learning to view PMSs as high-priced, heavy artillery that is wheeled out only when an agency plans to ask for more taxes. Can we, as PMS practitioners, use PMSs to show decision makers ways to use existing funding to (*a*) treat more kilometers, (*b*) improve overall pavement conditions, or (*c*) treat more kilometers and improve overall pavement conditions? After all, agencies are being asked to work in more new areas than ever before. Can we show the public that we are good stewards of its hard-earned dollars? Can we show the public that we are becoming more efficient and effective in our pavement work? Finally, can we show the public that our more efficient and effective pavement work has freed up money to spend on projects it wants? Positive answers to these questions would be beneficial in advocating PMSs.

Conclusion

Session participants were familiar with all the institutional issues presented to them. Participants were not surprised by any of the issues, and they came up with many solutions to these issues. However, despite the number of solutions and the technical expertise of the participants, the institutional issues are still serious.

It is hoped that this session gave participants some new ideas that will prove effective in eliminating or bypassing their institutional issues. Perhaps at the next international conference on managing pavements we will be able to have sessions describing how today's institutional issues have been resolved.

ACKNOWLEDGMENTS

The authors would like to thank the session's recorders—Jim Nichols, Dave Lowry, and Deborah Ortiz—for taking thorough notes of the table discussions, while still participating in those discussions. The authors also would like to thank all session participants for their opinions and enthusiastic discussions. Their efforts made this session a success.

WORKSHOP SESSION 14

Automated Road Monitoring: Progress on Surface Distress and the Multifunction Option

Sue McNeil (Leader), *Carnegie-Mellon University*
Luis Rodriguez (Recorder), *Federal Highway Administration*

The purpose of this workshop was to discuss the present status and future of multifunction automated road monitoring equipment and automated distress identification equipment.

Presentations in the Multifunction Automated Road Monitoring Equipment session addressed various views from a regulatory, supplier, and client (user) perspective. Panel discussions focused on the efforts to implement standards for selecting and specifying multifunction automated road monitoring equipment and road survey procedures and the advantages and disadvantages of purchasing, leasing, and contracting multifunction equipment.

Presentations in the Automated Distress Identification session addressed the status of the state of the art in automated pavement condition survey equipment, methods used to evaluate the reliability of this equipment, and present and future needs.

Multifunction Automated Road Monitoring Equipment

Regulation or Standardization Perspective

Robert Novak, chairman of a task group under ASTM Subcommittee E17.41, *Standard Guide for Classification of Automated Pavement Condition Survey Equipment*:

The standard is designed to classify automated pavement condition survey equipment that measures the longitudinal profile, transverse profile, and cracking of pavement surfaces operating at or near traffic speeds. The main purpose of the guide is to allow highway agencies, equipment manufacturers, and other highway-related organizations to classify the measuring capabilities of automated pavement condition survey equipment.

A rating system has been developed to rank equipment on the basis of the following:

1. Precision and repeatability of vertical measurement of longitudinal and vertical profiles,

2. Interval of longitudinal and transverse profile sampling,
3. Covered width of transverse profile, and
4. Crack width measuring capabilities.

The standard is expected to clear the ASTM full committee and be proposed as a standard in 1995.

Equipment Supplier Perspective

Bill Swindall, Roadware Corporation:

Reliability

Multifunctional vehicles are more complex and require high-quality equipment, well-documented maintenance procedures, well-trained operators, and complete testing and calibration of equipment before delivery.

Purchase Versus Lease Versus Service Contract

Staffing capabilities and pavement network needs should be used to determine whether to purchase or contract a vehicle. Owning a vehicle gives total control of vehicle schedule and operation. Contracting a vehicle limits production based on the supplier's schedule.

Specifications

Equipment, data, and performance are the key types of specifications that should be considered. Equipment specifications should define the type and number of components a client wants; data specifications should describe data type, amount, frequency and format and define data processing requirements; and performance specifications should describe required acceptance tests and minimum performance requirements.

Cost and Benefits

The cost of operating a multifunction vehicle is less than the cost of operating a group of unifunctional vehicles. In addition, multifunctional vehicles collect all data simultaneously, allowing better data correlation.

Client Perspective

Hungarian Experience

László Gáspár, Hungarian Institute of Transport Sciences, Ltd.:

Since 1991 Hungary has used Swedish RST equipment to collect pavement condition data. Equipment repeatability is evaluated annually. When RST equipment was evaluated against other equipment, RST pavement microtexture data and pavement cracking data did not correlate with data from the other equipment.

German Experience

Peter Carisius, German Federal Highway Research Institute:

Contracted or purchased equipment is randomly evaluated against other equipment owned by the Germans. The amount of data to be collected should be specified before data collection begins.

Through the years a series of contracts to contract pavement condition equipment has been let. Random testing and evaluation requirements have resulted in a substantial reduction in equipment cost per kilometer since the program was started.

FHWA–Texas Department of Transportation Test and Evaluation of Automated Pavement Condition Survey Equipment

Robert Harris, Texas Department of Transportation:

The primary purpose of this program was to test and evaluate fully automated pavement condition survey equipment. The secondary purpose was to test and evaluate semi automated and manually assisted equipment. The test was limited to the detection and measurement of pavement cracks. IMS/RST-PAVUE, Roadware Corp.–ARAN, PASCO USA, and Pave Tech participated in the test.

Test results will be tabulated side by side with manual condition surveys made using the SHRP/LTPP distress identification manual to simulate project-level analysis and with the Texas Department of Transportation PMIS manual rating system to simulate network-level analysis. Test results also will help users evaluate the accuracy and repeatability of the equipment.

Discussion Group Reports and Recommendations

Regulation Group Report

- Regulations should promote innovation.
- Regulations should provide ways to review and refine equipment procedures.
- Ways to give positive and negative feedback should be provided.
- Guidelines to match the standards levels required to collect data should be developed.
- Regulations should allow clients to determine how the cost of collecting data relates to data precision.
- Uniformity for calibration of equipment should be provided.

Supplier Group Report

- The choice of purchasing, leasing, or contracting equipment depends largely on clients' capabilities and their network sizes and requirements.
- Specifications should include calibration standards.
- Cost benefits will be achieved if a multifunction vehicle is used.
- Developing countries are better off leasing or contracting pavement condition survey equipment.

User Group Report

- There is a need to simplify data and find other uses for data generated by the equipment.
- There is a need to develop equipment that can collect thickness measurements and pavement deflection and calculate bearing capacity at highway speeds.
- There is a need to recommend different multifunctional configurations depending on clients' needs.

Conference Vice Chair Perspective

Bill Paterson, The World Bank:

Standards

- Classification standards help communication of data.
- Calibration standards help measure equipment performance and accuracy.
- Measuring unit standards help data reporting.

Service Contract Versus Ownership

- Clients should focus on product needs instead of process.
- Equipment can cope with technology changes.
- There is a competitive environment in terms of cost, service, and technology.
- Institutional issues are related to the degree of staff involvement a client can afford.
- Ownership and contracting decisions should be based on client needs and demands instead of available supply.

AUTOMATED DISTRESS IDENTIFICATION

British Experience in Developing and Testing Data Collection Equipment

Martin Snaith, University of Birmingham, United Kingdom:

Distress data in the PMS were unreliable and inconsistent; therefore, a program was set up to develop and calibrate equipment capable of collecting new rutting, roughness, and cracking data for the PMS. The main goal was to develop cost-effective equipment that can collect consistent and reliable data.

Equipment to collect rutting and roughness data was developed, tested, and calibrated in an acceptable manner. The cracking detection device is still under development.

Sweden's RST Capabilities

Ingomar Oloffson, RST Sweden:

The PAVUE RST is a vehicle that can evaluate cracking conditions at the same speed the data are collected (up to 90 km/hr). PAVUE uses a combination of video imaging and laser data to identify and classify pavement cracking.

Georgia DOT Experience

Wouter Gulden, Georgia Department of Transportation

The PMS in Georgia is based on rehabilitating 10 percent of the state's pavement network annually. The Georgia DOT pavement condition survey system is based on detecting distresses at their earliest stages. Pavement condition surveys of the entire network are performed annually.

The Georgia DOT currently needs automated pavement condition survey equipment that can analyze data in real time and equipment similar to the South Dakota Profilometer that can identify existing cross slopes and roughness. The department prefers to purchase equipment.

Researcher Perspective

Mark Ginsburg, U.S. Army Corps of Engineers Research Laboratory:

Mr. Ginsburg discussed the status of standards for the development of pavement cracking algorithms and pavement models. Researchers are beginning to look at machine algorithms that should improve the standardization of pavement condition survey equipment. They are beginning to agree on which machine algorithms do a better job of detecting pavement distress, which should result in better standards. However, current pavement models are too complex and not good for the development of machine algorithms. Also, the pavement models cannot analyze the amount of data generated by more sophisticated survey equipment.

World Congress

Ivan Scazziga, Viaconsult Ltd.:

The Permanent International Association of Road Congresses (PIARC) Technical Committee for Surface Characteristics always has been interested in traditional aspects of surface characteristics, such as rutting, skid properties, cracking, roughness, and texture. In preparation for the 1995 [PIARC] World Congress in Montreal, Canada, surface distress has been introduced as a new subject in the meeting's program. The purpose of including this subject is to report on the development status of various automated systems and discuss the improvements needed to enhance the technology.

Standardization and harmonization of automated systems will be discussed at the meeting. In the area of surface distress, there are many methods of performing visual inspections and an increasing number of automated systems. In the area of harmonization, there is a need for these automated systems to provide a common distress index, cracking maps, and other methods of counting the amount of cracks and identifying the areas where cracks occur.

A survey was conducted to identify the capabilities of various automated systems. Most of the responses described the systems' abilities to identify pavement cracking; not much was said about their abilities to identify potholes or bleeding. Another purpose of these systems is to replace the person who does visual inspections with a reliable automated system. However, we will continue to depend on visual inspections to identify deficiencies other than cracking.

The technical committee is currently tabulating the information from the questionnaires to identify operating conditions, the use of English units of measurement, operating speeds, data processing procedures, data processing time, data accuracy, and so on. Recommendations will be made in an effort to improve the harmonization of the systems on the basis of the information gathered from these questionnaires.

In addition, a workshop on automated image processing will be included in the congress.

Initiatives in Removing Barriers to Pavement Management

Brian R. McWaters, *Iowa Department of Transportation*
Gary W. Sharpe, *Kentucky Transportation Cabinet*

From the time pavements were first constructed, transportation engineers and administrators have managed them. Before the 1960s, pavement management was essentially reactive; that is, pavement engineers simply reacted to the needs at hand. There was no systematic attempt at managing the overall pavement system. Pavement management needs were addressed on a nonsystematic basis, sometimes on the basis of administrative priorities and sometimes on the basis of engineering priorities, but generally without a systematic approach at either the project level or network level. In the late 1960s and early 1970s, the term "pavement management" began to be used by pavement researchers and engineers to describe the entire range of activities associated with providing pavements to the public.

Today the term "pavement management system" implies a comprehensive, coordinated set of activities associated with the planning, programming, design, construction, maintenance, evaluation, and research of pavements. Figure 1 (*1*) shows the basic elements of a pavement management system and how these elements fit together. Before the Third International Conference on Managing Pavements, conferences in 1985 and 1987 presented information on potential barriers to implementation of pavement management systems. The barriers include resistance within an organization, funding problems, an incomplete understanding of pavement management, and a lack of commitment from management.

The 1985 conference presented in-depth views of various aspects of pavement management, including pavement policies, methods of decision making, information requirements, methods for ranking and optimization, maintenance effectiveness, and procedures for implementing a pavement management system. In a paper presented at this conference, Lee and Hudson (*2*) stated:

> An ideal pavement management system would yield the best possible value for the available funds while providing and operating smooth, safe, and economical pavements. The minimum requirements of such a system would include 1) adaptability, 2) systematic operation, 3) practical application, 4) quantitative decision making, and 5) feedback information. There is no ideal single Pavement Management System. Every highway agency presents a unique situation

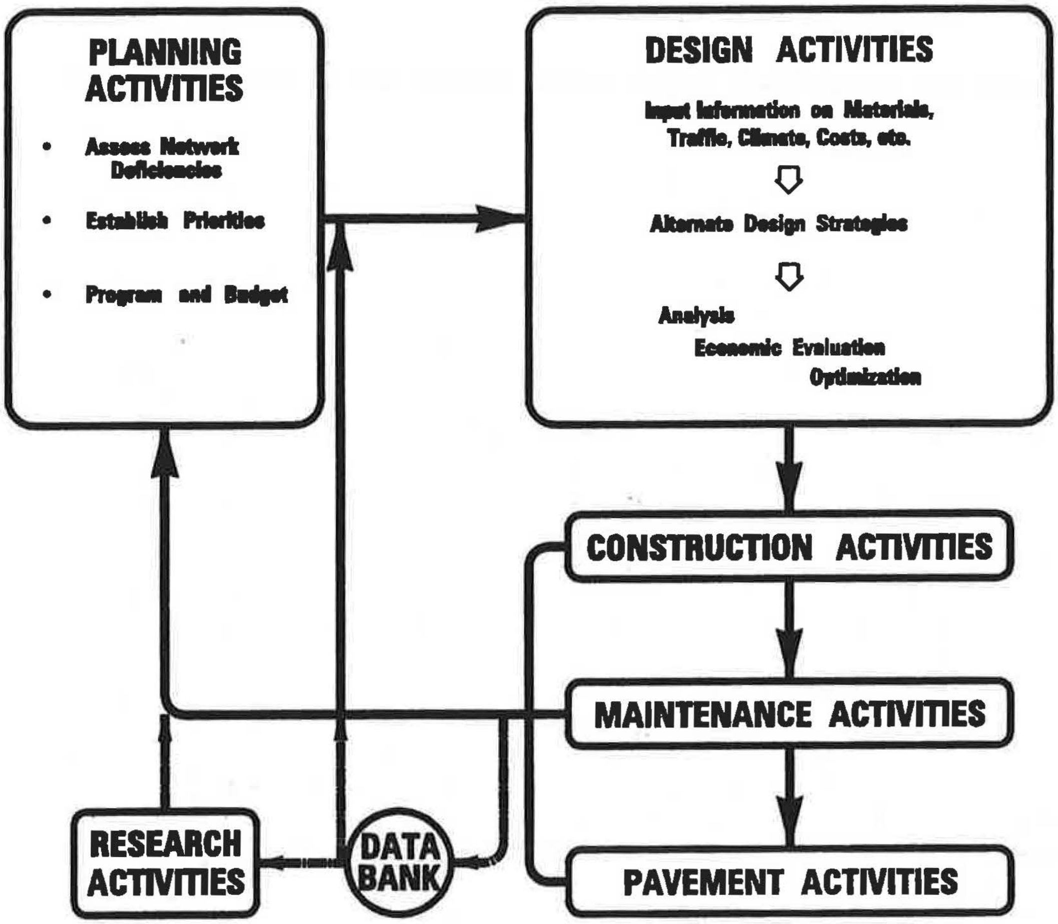


FIGURE 1 Basic components of a pavement management system (*1*).

with specific needs. Therefore each agency must define carefully what it wants from a pavement management system.

The information presented at the 1985 conference demonstrated that there is no such thing as an ideal pavement management system and that each agency or jurisdiction has unique needs.

Information presented at the 1987 conference demonstrated that lack of funding, communication, and commitment are barriers to implementation of effective pavement management. Francis Francois outlined some critical concerns for the implementation of a pavement management system. Mr. Francois recognized that adequate funding for pavement management may be a problem for implementation but that in many situations funding problems can be overcome. He noted that the absence of knowledgeable and committed top-level management may be more difficult to overcome than the lack of funding. He further noted that failure to properly communicate to policy makers, highway users, and the general public the reasons for supporting pavement management and the benefits to be obtained can deny pavement management the necessary political support needed for its success (*3*).

During development of the program for this conference, the selection of appropriate pavement management systems and identification of institutional and implementation issues were determined to be critical areas. Some of the barriers identified in 1985 and 1987 to implementation of pavement management systems continue to affect pavement management today.

The Federal Highway Administration mandated that all state highway agencies have pavement management systems by January 1993 (*4*). This mandate was further enhanced by the

1991 Intermodal Surface Transportation Efficiency Act (ISTEA). It is all well and good to require the development and implementation of pavement management systems. However, highway and transportation agencies usually are very slow to embrace new ideas and typically display a lot of inertia in implementation of new practices.

FACTORS INFLUENCING THE IMPLEMENTATION OF PAVEMENT MANAGEMENT

In a recent survey of state highway agencies, practices in pavement management were documented (*5*). The study indicated that approximately one-fourth of state highway agencies had advanced their pavement management systems to some type of network optimization level. The study also indicated that given the widespread application of pavement management, there is a need to promote the advancement of the science of pavement management. Specifically, the science of pavement management should have a common terminology, standard data collection procedures, and comparable data analysis methods. The study reported that individual agencies use different terminology, which prevents or impedes the routine exchange of information between one agency and another. The study also indicated that there was little sharing of technical information between the states. The study presented somewhat disturbing information in that there were groups within some agencies that did not completely understand the objectives and analysis models and associated software of their own pavement management systems.

The study concluded that there was little consensus at the national level, on the pavement management process or the analysis methods, let alone system objectives. Specifically, there was no consensus on the most important factors in the development of a composite measure for determining priorities for pavement maintenance, resurfacing, restoration, rehabilitation, and reconstruction activities. The study noted that distress was the primary consideration in most pavement priority indexes but that only about half the states used distress to determine priorities. The study further noted that various states used 1 or more of 11 pavement condition indicators as well as other measures of economic, traffic, and safety considerations.

Many of the issues initially identified as barriers to pavement management have not been resolved. Also, with the development of new technology, some technological barriers have been eliminated, and other barriers have evolved. Now that there is a federal requirement for all states to implement a pavement management system, some institutional barriers to pavement management have been eliminated. There are new areas of concern in pavement management, however, including standardization, uniformity of pavement management data, data collection and reporting, metrication, the interrelationships between the pavement management effort and the planning function, methods to continue trends in pavement management with ever-changing equipment for collecting data, and the electronic format for information transfer. The definitions of pavement quality and performance vary from agency to agency. The authors believe that more clearly defined definitions of pavement quality and performance will enhance communication between administrators and technical staff and lead to an improved understanding of the pavement management process and the uses of the results of the process.

Organizational Influences on Pavement Management

The organizational structure of a given agency often is a primary barrier to an effective pavement management system. As noted in Figure 1, a pavement management system involves the interaction of many groups within a highway agency. The location of these critical participants within an organization can have a significant impact on the success of a pavement management program. In most highway agencies, the pavement management unit is responsible for collecting or coordinating the collection and dissemination of pavement information. The location of the pavement management unit and its ability to interface with all critical participants often is a reflection of the commitment of top-level management to the pavement management effort.

In some instances, top-level management changes, and agendas change as well. Today there is more emphasis on total quality management, and reorganizations are occurring on the basis of customer needs. It is important for pavement managers to be at the forefront of these efforts and to keep up the high level of technical and engineering expertise required to maintain their pavement management process. In addition, pavement managers must work within the structures of their organizations to provide the greatest level of quality and service to all customers.

The size of the pavement management system staff also is a reflection of commitment to pavement management. In most highway agencies, the pavement management system is somewhat decentralized, with planning, pavement design, construction, maintenance, and the pavement management unit being in various places in the organization. The decentralization of various pavement management functions can lead to competition among various departments within the highway agency.

It is often said that no matter how sophisticated technology becomes, things get done by people. Management of personnel resources is critical to the success of pavement management. Highway agencies continue to suffer from a deteriorating experience base because of retirement of experienced personnel or other forms of turnover. The lack of training of new and inexperienced personnel is another problem. This can only be countered by continuing education for all persons involved. Technical personnel need to keep developing their technical skills. Administrative personnel need continuing training to better understand the capabilities, applications, and benefits of the pavement management system.

As stated previously, transportation agencies always have managed pavements. The term "pavement management" implies the systematic management of an agency's pavement resources to provide the best service to the public. Implementation of systematic pavement management varies from agency to agency. Most agencies are fragmented, with various elements of their pavement management systems operating in various units. The cost of reorganizing these units into a comprehensive pavement management unit, however, may outweigh the potential for improved efficiency. Consistent funding of pavement management activities is essential.

In some cases, the policies of an agency may preclude the effective application of some pavement management practices. Political and administrative decisions may override decisions based on pavement management data. Policy and fiscal constraints may require that pavement repairs be on a "worst-first basis," even though the optimum approach using pavement management data might dictate a different strategy.

Understanding Pavement Management

A comprehensive pavement management system is a tool. Perhaps the most significant barrier to effective pavement management is a lack of understanding of pavement management. Agencies have worked diligently to develop pavement management processes. However, the ultimate success of a pavement management system is measured by the product evolving from the process.

Competition and/or conflict between the process and the product can be a significant barrier to the successful implementation of a pavement management system. It is important for an agency to develop and implement a pavement management system that fits the agency's goals. An agency must define the objectives of its pavement management system and develop its pavement management process so that the desired products evolve from the system. Once a process that results in the desired product has been developed and implemented, communication and presentation of results is critical.

The lack of understanding of the interpretation and communication of pavement management information is one of the most significant barriers within an organization. In short, administrators may be reluctant to use the results of pavement management evaluations because they do not understand pavement management. The authors believe that this lack of understanding exists at all levels of the communication chain.

It is important that technical information be provided to administrators as clearly and concisely as possible. Our decisions typically have been based on past experience. For the most part, we have done a poor job of documenting past experience with pavements. This lack of documentation, combined with a lack of consistency in pavement management practices from one agency to another, further hampers communication of pavement management information. Therefore, it is important to develop appropriate procedures for communicating pavement management information within an organization.

Extensive training and education must continue for all involved in the pavement management process. Technical training is necessary for keeping up with an ever-changing technology, and communication training is necessary for developing effective methods of presenting data and other information. Education for administrators is necessary to help them address the interrelationships between policy and pavement management.

It is important to match the communications and presentations to the audience and to present pavement management information so that the information and the consequences of decisions and actions are understood.

External Influences on Pavement Management

In many instances, barriers to pavement management are beyond the control of those who direct the pavement management process. Social, political, and administrative considerations significantly influence the process. In addition, shifting priorities and changing regulations, both from within and outside the agency, influence pavement management. There is little the pavement manager can do to control outside influences. Additional effort is warranted by pavement professionals to educate administrators about the pavement management process. It is important that all involved in the process understand the benefits to be derived from using pavement management information. It is also essential that administrators understand the strengths and weaknesses of the process so that they make the most informed decisions.

Finally, ever-changing technology, typically considered an enhancement to pavement management, can sometimes be a detriment. In some situations, as technology forces the use of new equipment, trends identified from old data are lost because of lost links between old and new equipment. Experience is one of the pavement manager's greatest assets. As we evolve and introduce new equipment into the pavement management process, we must take special care to keep track of trends and to maintain our experience base as we move into the future.

Uniformity and Standardization

There is a lack of consistency in pavement management practices from one jurisdiction to another. In part this lack of consistency stems from differences in processes and desired products among pavement management systems. Lack of standardization and harmonization in pavement management is a significant barrier to transferring data from one jurisdiction to another and to performing comparative data analyses. Data consistency requires protocols for data collection, quantification of performance and pavement condition data, uniformity of procedures for economic analyses, and procedures for communication of data. In addition, determination of baseline values and threshold values, which will allow comparative analyses of data, is required. No guidelines exist for conducting economic analyses in the highway community.

The lack of consistent practices in pavement management demonstrates the need for standardization and harmonization. Guidelines from regulatory agencies on minimum requirements for pavement management are needed. The 1990 AASHTO *Guidelines for Pavement Management Systems* (6) are the beginning. With added emphasis on standardization, uniformity, and the development of more detailed guidelines for pavement management systems, the communication of data and results of pavement management should be enhanced and should facilitate more universal application.

CONCLUSIONS

The future presents a challenge to pavement management professionals. Changes in equipment, technology, instrumentation, and means for reference orientation such as global positioning technology are among the issues that must be addressed in the future. If pavement management is to continue to succeed, pavement management personnel must find ways to integrate new equipment into the pavement management process without compromising the data trends identified by old equipment. As technology develops, the need for continued communication with equipment manufacturers and suppliers becomes more critical. There is a need for extensive efforts to correlate the old with the new.

We have witnessed the tendency of administrators and engineers to develop pavement decisions on the basis of their individual experiences, without looking at the overall picture that can be identified only through systematic pavement management. In some situations, there is a reluctance to base decisions on gathered data and to consider detailed economic analyses in the decision-making process. At times, state agencies seem to be reluctant to believe in their data. We need to move into the 21st century and start basing our decisions on the net effects of our assets. Asset management is the way of the future, whether in the economic life of a pavement design or a life-cycle cost analysis. We must make proper engineering decisions that address problems so that the economic bases of analyses are sound.

We have a tremendous challenge not only to remove the barriers that have been with us in the past, but also to face and meet the challenges of the 21st century. We can accomplish this through continuing research in developing engineering solutions to technical problems. We need to develop the training and educational programs necessary for pavement engineers to better understand the science of pavement management. If we do not adequately understand this science as it relates to the overall goals in our individual organizations, how can we effectively communicate the results, findings, and recommendations of the pavement management process to administrators who control the lifelines of pavement programs? We must continually learn to be better communicators. As we move to the 21st century, we need to learn from the past and use the technology of the future to achieve the ultimate goal of a rationally based pavement management system.

REFERENCES

1. Haas, R., and W. R. Hudson. *Pavement Management Systems.* McGraw-Hill, Inc., New York, 1978.
2. Lee, H., and W. R. Hudson. Reorganizing the PMS Concept. *Proc., 1st North American Pavement Management Conference*, Vol. 1, 1985.
3. Francois, F. B. Future Organizational and Resource Requirements for Managing Pavements. *Proc., 2nd North American Conference on Managing Pavements*, Vol. 4, 1987.
4. *Federal Aid Highway Program Manual.* Transmittal 428, Vol. 6, Chapter 2, Section 4, Subsection 1. FHWA, U.S. Department of Transportation, 1989.
5. Irrgang, F. C., and T. H. Maze. Status of Pavement Management Systems and Data Analysis Models at State Highway Agencies. In *Transportation Research Record 1397*, TRB, National Research Council, Washington, D.C., 1993.
6. *Guidelines for Pavement Management Systems.* AASHTO, Washington, D.C., 1990.

Developing Innovations in Thin, Very Thin, and Ultrathin Overlays: The Montreal Experience

Norman Henry Danylo, *City of Montreal Public Works*

In 1988 the executive committee of the city of Montreal approved a policy proposal concerning the management of Montreal's network of roads and sidewalks. The proposal covered a 10-year span and included a funding plan that earmarked a total of $350 million for this purpose.

Among the many clauses of that policy, two statements were to help the Montreal Public Works Department step out in the field of innovation. One statement set out maintenance priorities: first, conservation; second, prevention; and third, rehabilitation. The second statement directed the department to study, evaluate, and implement new treatments for roads, especially in the category of conservation maintenance.

After resolving many issues through discussions and meetings, the public works department believed it could proceed with various calls for proposals. In 1991 the call was for very thin overlays (15 to 30 mm); in 1992 the call was for ultrathin overlays (less than 15 mm); and the department is now in the process of a similar call for proposals for thin overlays (30 to 50 mm).

Approach

In a traditional approach, contractors furnish bids on projects and contracts in which the object or intervention is clearly and rigidly defined by specifications. Further, these interventions usually are well known and have been used in other projects or in neighboring areas.

The aim of the call for proposals is to determine which contractor can do the described work at the lowest possible price. This conservative approach does not encourage the development of new technology.

The approach that the Montreal Public Works Department favored was to establish a real partnership with private enterprise, one that sought to use its expertise and knowledge. Emphasis, therefore, was put on the results we sought, leaving how these results were obtained to the proponents. We were seeking the best value in an intervention, not necessarily the one that had the lowest cost per square meter.

PREPARATIONS

To overcome the many objections to our approach, a series of meetings was held with managers involved in different aspects of the contract award process. The main objection to our approach was that it did not award a contract to the lowest bidder. Out of these meetings, the following observations or decisions were made that allowed the public works department to proceed with calls for proposals:

1. The legal department opined that "... if the charter of the City does not specifically forbid an action, then that action may be permissible." This encouraged us to continue with our approach.

2. Contract awards for most professional services are based on an evaluation of the proposals, on the relevant experience of members of the firm, and on past performance. Price is not necessarily a determining factor.

3. Contract awards in Montreal for snow removal and for solid waste removal are not necessarily given to the lowest bidder. Indeed, when the city issues a call for proposals for these contracts, it offers many contracts in a single call for proposals, and bidders can bid on as many contracts as they want. However, bidders can only receive as many contracts as they can handle with the equipment they own.

The final award is determined through an operational research method that guarantees that the entire award is at the lowest price. Thus, the lowest bidder for a specific contract will not necessarily get that contract. This process had once been challenged in the courts, but the city had won its case.

4. The city clerk insisted on a public opening of bids and announcement of proposal cost at that opening, even though the cost associated with the technique was not to be used as a determining factor in the assessment of the technique. However, because the public works department proposed to set a ceiling for the cost of any contract and intended to set a minimum coverage, the clerk offered a solution. The department would ask for two sealed bids. The first envelope would contain the total cost of the proposal; the second, to be opened only after technical evaluation was complete, would state the square meters to be treated for the stated price.

After these meetings we decided to proceed in 1992 with our first call for proposals. This was followed by similar calls in 1993 and 1994. We also decided to hire a consultant to assist in the process; take the required samples before, during, and after the work; and prepare the performance reports during a 3-year period.

HIGHLIGHTS

Following are some overall parameters for and particular clauses of the calls for proposals.

1. The budgeted amount for all proposals was established at $350,000 in 1992 and 1993 and $500,000 in 1994.

2. No proposal that exceeded a certain ceiling would be retained. For very thin and ultrathin overlays, the ceiling was set at $50,000; for thin overlays it was set at $100,000.

3. No proposal that did not provide a minimum coverage of 5000 m^2 would be retained. In 1992 and 1994 the minimum was 5000 m^2; for the ultrathin contracts of 1993, the minimum was 8000 m^2.

4. In all cases, the result expected of the treatment was "to renew in a street still in good condition its original qualities of impermeability, smoothness and adherence."

5. The streets that might receive the treatment were not identified. Their general characteristics, however, were stated as follows:

   a. They would be on the same type of soil, representative of Montreal area geology.

   b. The structure of the road would be the same (i.e., bituminous cement overlay on a cement concrete base).

c. The visual rating of selected roads, a standard known to all bidders, would be announced. In the public works department's system, a road in excellent condition has a rating of 0.5; one in the worst condition, 5.00.

d. Ultrathin overlays were apposed on streets with ratings between 1.5 and 2.0, very thin overlays on streets with ratings between 2.1 and 2.6, and thin overlays on streets with ratings between 2.7 and 3.2.

e. The DTN would be more than 4,000 or, if under that amount, the road would be used regularly by city buses.

6. Each enterprise could submit as many proposals as it wanted. Each proposal, however, had to be a distinct bid, accompanied by a specific guarantee.

7. After the 1992 call for proposals, the public works department required contractors to test the overlays on their property. Once the city accepted the test, the contractors could proceed on city streets. This cost was borne by the city if the proposal was successful.

8. Finally, each bidder was entitled to make an oral presentation to the technical evaluation committee.

Analysis

A three-man team was selected to review and analyze the various proposals. One represented the city's laboratory; another, the group responsible for surveillance of the work; and another, the division that would oversee the entire process. The team was assisted by a subcommittee of four persons considered experts in pavement maintenance.

Before the call for proposals was launched, the enlarged committee established the following admissibility and technical criteria. These, in turn, were made known to all bidders.

Proposals would be rated on the basis of potential for future use on Montreal streets, degree of innovation, resemblance to other techniques proposed by the same contractor, and the realism of the tendered price.

The technical evaluation of the proposals would address experience of the personnel, availability of equipment, the quality assurance proposal, degree of innovation, experience of the contractor with similar techniques, and technical documentation provided with the bid.

Once the technical evaluation was completed, for techniques that were deemed technically acceptable, the second bid envelope would be opened and the following additional considerations would be applied: unit price of the bid and length of the guarantee.

The rating sheet was furnished as part of the call for proposal documents.

Winners

Fifteen proposals on very thin overlays were received from six contractors by the deadline. After technical evaluation, 10 proposals remained, and 7 were selected.

Seven proposals on ultrathin overlays were received from five contractors by the deadline. After technical evaluation, five proposals remained, and five were selected.

Seven proposals on very thin overlays were received from four contractors by the deadline. After technical evaluation, five proposals remained, and four were selected.

Implementation

To fully appreciate the value of each technique and to be able to draw some conclusions at the end of the trial period, the following plan of action was undertaken by the consulting firm retained for this project:

- Effect a detailed survey of the street sections selected for the trials before any intervention.

- Effect a close surveillance of all work phases.
- Effect a detailed survey of the street sections selected for the trials immediately after the execution of work and 1, 2, and 3 years after the execution of work.

Surveys

The prework and postwork surveys are a means of observing the behavior of street sections that have underdone new or standard treatment. The following surveys were chosen.

Cartographic Survey

A detailed surface condition survey of each street section was undertaken before applying new treatments. The survey included the location of all cracks, visible repairs, utility holes, and so on. Future surface condition surveys would then establish whether new defects are reflections of the underlying defects or are directly attributable to the new technique.

Because the degree of cracking is slightly different from one street to the next, it was decided that the consultant would compare the progression of the cracks for each section and not compare the progression against other techniques. The lower the progression, the better the treatment is against water infiltration.

Mays Survey

The Mays meter was used to measure riding comfort in each lane. The increase or decrease in riding comfort is calculated as a percentage so that techniques can be compared one on one. The treatment that results in a good riding comfort index at the start and a slow depreciation of that index over time is preferred.

Rutting Survey

Rut sizes were calculated every 25 m in each direction and in each lane. The treatment that results in little or no rutting at the start and a slow buildup of that defect over time is preferred.

Scrim Survey

Initial readings of slipperiness were taken with the British pendulum. Further readings with the British pendulum and with the SCRIM will be taken during the trial period. The treatment that results in a low slipperiness coefficient and maintains it best is preferred.

Surveillance of Work

Because later defects might be caused by conditions at the time the work was executed, close attention was given to this phase. Attention was paid to the sealing of cracks with sealant or asphalt, the removal of deteriorated asphalt, and any milling operation.

These activities or events were traced on a series of plans. Future surveys will help establish if surface defects are the result of preparatory work or the treatment itself. In addition, more than 200 photographs and approximately 20 hours of videocassette footage were taken during execution of the projects.

Material Sample Analysis

Core samples were taken after work was completed, and the following information was gathered or tests were performed: thickness of the treatment, density of the mix, rutting resistance, and compaction. Also, the macrotexture of the end product was measured using the ASTM sand height method.

Results

The Montreal Public Works Department will share its successes with very thin overlays in fall 1995 and will report if a technique has actually failed. No techniques so far have, and we are reasonably optimistic that we will uncover several fine techniques that will help the city of Montreal renew its network of roads.

British Columbia's Experience with Contracted Road and Bridge Maintenance

Earl A. Lund, *Ministry of Transportation and Highways, Victoria, British Columbia*

The government of the province of British Columbia announced in October 1987 that the maintenance of all roads and bridges would be privatized (contracted to private companies). An offer was made to all maintenance workers employed by the government that if they formed employee groups, they would be first in line to negotiate contracts in each of the 28 contract areas. Employees also were told that if they chose not to accept work from the contractors, the government would find them other work within public service.

The decision to privatize the maintenance of roads and bridges was based on the premise that contractors competing for work would be better able to control costs and bring innovations to equipment, staffing, and methods.

The British Columbia Ministry of Transportation and Highways developed contract principles and end-product maintenance specifications. Contracts were to be negotiated with qualified private contractors if an employee group did not form or if negotiations broke down with an employee group. All contracts were 36 months in length. The first contract was activated on September 1, 1988, and the last one on April 1, 1989.

The contracts were lump-sum types with monthly payments due at the end of each month. There was no provision for dispute resolution or for monitoring the management capability of the contractor. All equipment was either sold to the contractors or leased in cases in which newer essential units such as graders and plow trucks were needed. All materials, including produced sands and crushed aggregate, were sold, but the gravel pits and yard facilities were leased to the contractors.

Round 1

At the time of privatization the ministry had comprehensive maintenance management and equipment management systems in place. These systems provided a solid basis for establishing the government's direct cost for each contract. Negotiations involved the difference between full government costing and the prices offered by the contractors. At the completion of negotiations of all Round 1 contracts, the government announced a direct savings of $21 million, which incorporated the projected inflation rates from 1988 to 1991. Ninety percent of the 2,700 ministry employees who were affected directly accepted employment with the contractors, and the rest were placed in other government employment.

A summary of Round 1 contractor types and contract prices is given in Table 1. Several contractors performed at high levels, many at average levels, and a few at less than satisfactory levels. Three contracts were poorly managed. Although two contracts provided acceptable performance, they experienced financial and employee relations problems. The third contract was defaulted by the ministry because of poor performance.

Round 2

The second round of contracts was negotiated by the ministry during 1991, using three negotiating teams backed by a project office that provided all support services. The number of bids received for each contract area as well as a breakdown of the types of contractors is given in Table 2.

Round 2 was characterized by 15 of 28 contract areas receiving new contractors. Only 13 incumbents retained their original contract areas. Round 1 employee groups were able to increase their number of contracts in Round 2 from 10 to 11 areas. One contract was adver-

TABLE 1 Round 1 Contracts (September 1, 1988, to March 31, 1992)

CONTRACT NO.	EMPLOYEE GROUP	EMPLOYEE GROUP WITH A CONTRACTOR AS MINOR PARTNER	PRIVATE CONTRACTOR	CONTRACTOR	CONTRACT VALUE ($ MILLIONS)[a]
1			x	A	30.40
2			x	B	23.25
3			x	B	27.21
4			x	C	22.39
5			x	C	8.53
6		x		D	41.06
7			x	E	33.29
8			x	F	35.20
9			x	G	26.84
10			x	G	39.86
11			x	H	28.90
12			x	G	25.26
13			x	J	37.06
14		x		K	30.62
15			x	L	27.62
16			x	L	32.22
17		x		M	29.81
18			x	N	26.33
19	x			P	36.57
20	x			P	16.78
21		x		Q	36.74
22			x	N	30.69
23	x			P	19.76
24	x			R	16.39
25	x			S	30.15
26			x	T	11.73
27			x	U	7.42
28		x		V	23.91
Total	5	5	18	20	

[a]Average contract value was $26.2 million.

TABLE 2 Round 2 Contracts (September 1, 1991, to March 7, 1994)

CONTRACT NO.	BIDS RECEIVED[a]	SAME CONTRACTOR	ROUND 1 CONTRACTOR IN ANOTHER AREA	NEW CONTRACTOR	SAME AREA EMPLOYEE GROUP	DIFFERENT AREA EMPLOYEE GROUP	CONTRACTOR
1	3	x					A
2	4	x					B
3	3	x					B
4	2	x					C
5	4		x				L
6	3	x			x		D
7	7		x			x	P
8	3			x			X
9	2		x			x	K
10	1	x					G
11	3		x				G
12	3		x				J
13	5		x			x	K
14	5	x			x		K
15	4			x			Y
16	2			x			Y
17	3	x			x		M
18	2			x			Z
19	2			x			Z
20	5		x				L
21	6	x			x		Q
22	2	x					N
23	2	x			x		P
24	2	x			x		R
25	4		x				R
26	3		x			x	S
27	2	x					U
28	5		x			x	P
Total		13	10	5	6	5	18

[a]The average number of bids received was 3.2.

tised each week, which began a schedule of steps culminating in the signing of a contract on the date the previous contract expired.

The basic bidding process took 130 days, with 18 days for notice and initial proposal submission, 7 days for initial proposal evaluation, 35 days for detailed proposal preparation and submission, and 7 days for contract finalization and mobilization.

The contracts in Round 2 varied in length so that their completion dates would be 1 week apart in 1994. Each contract contained a provision for a 2-year extension at the sole discretion of the minister. The criterion for an extension was a rating of at least 0.85 in the quality assurance and management assurance systems.

Analysis of Rounds 1 and 2

The main improvements made between the Round 1 and Round 2 contracts were (*a*) the clarification of some road maintenance standards, (*b*) the rewrite of bridge maintenance standards, (*c*) the inclusion of the contractor's business plan in the contracts, (*d*) the requirement for the contractor to have in place and use a complete maintenance management system, and (*e*) the fact that Round 2 contractors were required to offer employment to Round 1 contractor employees on the same terms and conditions.

The financial benefit of the privatization initiative to the government can only be realized by a healthy competitiveness in a sufficiently sized industry. In Round 1 there were 20 contractors for the 28 contract areas, whereas in Round 2 there were only 18 successful contractors. In both rounds there was a maximum of three contracts allowed for each contractor.

Bidding information for Round 2 contracts is summarized in Table 3. There seems to be no correlation between the sequence of bidding and the variation between the two lowest bids.

The total price for Round 2 contracts was within 1 percent of the ministry's estimated contract cost, based on Round 1 costs adjusted for inventory changes and inflation. Hence, the competition among bidders did not produce any significant savings between Round 1 and 2.

There should be concern about the reduction in the number of successful contractors and the fact that only two bids were received in nine contract areas and only one bid in one other contract area. It is generally conceded that it costs a contractor about $50,000 to bid on a contract area, which is 0.2 percent of the average contract price of $26 million, which should not be a detriment to the bidding procedure.

Round 3

In January 1994 the British Columbia government approved the extension of all 28 contracts for 1- or 2-year periods. Contractors that had met the extension criteria provided to them in March 1993 were invited to submit 2-year extension proposals. All other contractors in good

TABLE 3 Round 2 Contracts (In Order of Requesting Bids)

CONTRACT NO.	RANGE HIGH TO LOW BIDS	LOW TENDER ($ MILLIONS)	DIFFERENCE BETWEEN LOW BID AND SECOND-LOWEST BID ($ MILLIONS)
18	.89	35.90	.89
1	10.45	32.98	1.71
8	6.30	36.45	2.15
10	0	40.95	0
19	3.54	34.41	3.54
12	2.32	24.90	.50
6	3.02	37.61	.38
23	2.94	19.99	2.94
2	9.6	26.45	.25
22	3.34	30.86	3.34
11	3.85	31.01	1.48
13	5.05	32.00	.37
3	5.16	27.22	1.11
9	1.25	25.45	1.25
25	9.85	30.90	.30
24	.36	16.97	.36
14	1.75	33.85	.06
27	2.16	6.94	2.16
16	2.60	31.35	2.60
26	4.19	14.80	1.10
4	.28	24.97	.28
15	1.66	23.19	1.11
20	1.44	16.49	.46
17	.77	28.08	.09
5	.90	7.10	.90
28	10.61	20.79	3.19
21	5.71	34.49	0.22
7	4.07	30.69	1.41

standing were invited to submit 1-year extension proposals. Of the 28 contracts, 16 received 2-year extensions, 11 were accorded 1-year extensions, and one was declined an extension because of a partial default standing. Negotiating of extensions currently is under way, and the results are not yet available. The ministry is experiencing difficulties meeting the estimated cost of the contracts.

Maintenance Standards

All road and bridge maintenance standards, which are end-product types with response-time triggers, include some method or recognized procedures. Either a list of acceptable materials is used for proprietary products or the ministry's construction specifications are used for items such as ready-mix concrete, culvert pipe, and crushed gravel. There are 8 groupings of the 66 road standards: surface, drainage, winter, roadside, traffic, structure, emergency, and inspectional maintenance.

Three kinds of maintenance services are included in the contract price: routine maintenance, annual plan maintenance, and emergency services. Rates are included for additional maintenance services, which are rarely used, and for authorized emergency services above the financial caps included in the contract price.

The contractor is responsible for providing all administration, work identification, management, and quality control for maintenance services. The British Columbia Ministry of Transportation and Highways employs 140 area managers who carry out a quality assurance program (QAP) to assess the present state of the infrastructure and the quality of work performed (in-process and end-product). These area managers also evaluate the contractor's management practices against his or her business plan, which is part of the contract, using the management assurance program.

In Round 1 of the maintenance contracts, the ministry ascertained that many contractors lacked the knowledge or ability to manage their businesses. As a result, a much greater emphasis was placed on the requirement that contractors manage the identification, scheduling, and quality control of maintenance work to meet the standards.

Summary

When the British Columbia government decided to privatize road and bridge maintenance in 1987 it was hoped that private industry would become competitive. On the basis of ministry costs calculated by a large national accounting firm and adjustment of 1987–1988 costs for inventory and actual inflation rates, it appeared in early 1992 that only minor savings had been realized (less than 1 percent). In 1993 the government commissioned another review of the process. The report had not been released at the time of this conference. However, the minister of transportation and highways stated that the review would contain a minimum mandate to investigate the costs of maintenance services, performance of contractors, and treatment of maintenance employees.

Former ministry employees who are now contractor employees and, in some cases, shareholders, are generally satisfied with their remuneration. Some, however, still prefer to be ministry employees. The concerns usually expressed by these employees are the stress and uncertainty that surrounds each bidding period and the transfer of employment to the succeeding contractor, with no guarantee of continued employment.

The ministry recognizes that there is a more consistent maintenance level due to the monitored application of detailed maintenance standards and more uniform contract administration. There is little public pressure to return the services to the public sector, yet there is no great vocal support for the privatization initiative. Hence, the service to the public is more consistent, but the costs are less than before privatization.

Warrantied Pavement on an Interstate Highway in California

Bernard A. Vallerga, *B. A. Vallerga, Inc.*

During the 1993 construction season, the California Department of Transportation (Caltrans) solicited bids for state highway work using the principle of "warrantied pavements" on several overlay construction projects. One of these projects—the Sims Project—was located on Interstate 5 north of Redding, running from 1.2 mi south to 0.8 mi north of the Sims Road undercrossing. Essentially, construction was to consist of placing two lifts of an asphalt concrete overlay on existing portland cement concrete pavement, which was to be "cracked and seated." Both lifts were to be 0.15 ft (1.8 in.) thick. The first lift was to be made of asphalt concrete (Type A) and the second of rubberized asphalt concrete (Type G, asphalt rubber).

The warranty was to be limited to the asphalt concrete paving itself, and the contractor was to agree to warranty the performance of its asphalt concrete paving for 5 years. Enforcement of the warranty was to be based on defined performance criteria incorporated in the special provisions (*1*) of the project.

Terms of Warranty

As stated in Section 2-1.04, Warranty and Bonds, of the special provisions for the Sims Project, a "material and workmanship warranty for a period of 5 years from the date of completion of planned construction" was called for, with the caveat of "no additional compensation."

Terms of the warranty, which were stated in Section 5-1.15 of the special provisions, are summarized as follows:

1. The contractor was to warranty the materials and workmanship entailed in furnishing and placing asphalt concrete (Type A) and rubberized asphalt concrete (Type G) as shown in the plans, as specified in Caltrans standard specifications, and as modified in the special provisions.

2. If any area of the asphalt concrete pavement proved to be defective or failed to perform properly, as defined in the special provisions, within 5 years after construction was completed, the contractor was required to "repair the asphalt concrete pavement in such areas considered defective" as specified in the special provisions.

3. During the 5-year warranty period, the responsibility of the contractor "for any liability imposed by law for injuries or death of any person including but not limited to workmen and the public, or damage to property" was to be limited to "actions resulting from defects in the constructed asphalt pavement and to actions resulting from defects, obstructions or from any other cause during actual progress of warranty work."

4. The engineer was to decide "all questions which arise as to the performance of asphalt concrete pavement" as defined in the subsection Performance Criteria and Repairs.

5. The engineer was to notify the contractor in writing of any needed repairs, and the contractor was to "initiate the needed repairs within 15 calendar days after receiving said written notification" and was to "diligently pursue said repairs to conclusion."

Performance Criteria

The following performance criteria, which were to apply to the work during the warranty period, were delineated in the special provisions for the Sims Project and are presented verbatim:

> Rutting. Rutting is a longitudinal surface depression in the wheel path(s). Rutting shall be measured perpendicular to the center of the road, in accordance with the last two paragraphs in Section 39-6.03, "Compacting," of the Standard Specifications. Ruts in asphalt concrete pavement greater than 0.04-foot deep, shall be repaired as specified herein.
>
> Raveling. Raveling is the wearing away (loss of aggregate) of the pavement surface. Raveling in asphalt concrete pavement shall be repaired as specified herein.
>
> Flushing. Flushing is the occurrence of a film of bituminous material on the asphalt concrete pavement surface. Flushing that results in a coefficient of friction less than 0.30 as determined by California Test Method No. 342 shall be repaired as specified herein.
>
> Delamination. Delamination is the loss of the bond between layers of pavement. Delamination in asphalt concrete pavement shall be repaired by cold planing the asphalt concrete pavement to a depth not less than the affected depth for the full lane (or shoulder) width of the affected lane (or shoulder), and replacing the removed pavement with rubberized asphalt concrete (type G asphalt rubber).
>
> Cracking. Cracking is the occurrence of narrow breaks or fissures in the asphalt concrete pavement. Cracks which develop in the asphalt concrete pavement shall be prepared and sealed as specified in "Seal Random Cracks" elsewhere in these special provisions.

Interpretation of the degree of raveling, delamination, or cracking at which repair is needed is left to the judgment of the engineer.

Repair Criteria and Warranty Work Requirements

The repair criteria imposed on the contractor also were set forth in the special provisions. The following summarizes criteria related to the scope of this paper:

1. Any single area of asphalt concrete pavement greater than 10 ft^2 that fails to meet listed performance criteria "will be considered defective and shall be repaired as specified."

2. Any asphalt concrete pavement "containing cracking in excess of 1/4 in. wide, regardless of length, will be considered defective and shall be repaired as specified."

3. Repairs of defective asphalt concrete pavement will normally consist of "cold planing the asphalt concrete pavement to a depth of not less than 0.15 ft for the full lane (or shoul-

der) width of the affected lane (or shoulder) and replacing the removed material with rubberized asphalt concrete (Type G asphalt rubber)."

4. The total length of repairs in any one lane or shoulder is not to exceed 30 percent of the total length of the lane. If so, the entire lane is to be overlain with an additional layer of asphalt concrete (Type G asphalt rubber) 0.15 ft thick.

The work requirements called for under the warranty concept as given in the special provisions are as follows:

1. The contractor "shall assume control over many of the details of asphalt concrete pavement normally controlled by the Engineer." In effect, the contractor is to decide all questions related to the quality and acceptability of materials used and may use the Caltrans-recommended materials and construction specifications. However, "compliance with the Caltrans specifications will not relieve the contractor from the provisions of the Warranty."
2. The contractor prepares and submits the job-mix formula (JMF) it will use to the engineer, but will itself decide any questions related to the quality and acceptability of "materials furnished and work performed with regards to asphalt concrete surfacing." Moreover, the contractor must perform the testing and quality control procedures called for in the Caltrans manuals and make the results of such testing immediately available to the engineer. However, changes from one mix design to another cannot be made during progress of the work unless a new JMF is developed and submitted.
3. The contractor must agree that the thickness of each type of asphalt concrete shown on the plans is a "minimum thickness." However, meeting this requirement is not to be "construed as a warranty, expressed or implied, as to the required minimum thickness necessary to meet the criteria" set forth in the warranty section of the special provisions.

Contractor's Response to Challenge

The contractor, Jack Baker, of W. Jaxon Baker, Inc., located in Redding, accepted the challenge by submitting a did and signing a contract in a joint venture with the J. F. Shea Co. to perform the work under the aforementioned warranty. However, Baker did so only after he was sure that the asphalt concrete mixtures produced by his asphalt plant, using the crushed aggregate from his Fawndale quarry, would have a very high probability of meeting the performance criteria of the warranty. The asphalt concrete had to sustain the heavy traffic and widely ranging climatic conditions at the Sims Project site without showing any significant signs of damage during the 5-year warranty period, and, preferably, far beyond it. Although Baker's conventional asphalt concrete mixes, as designed by the Caltrans district laboratory in Redding, had performed well on other sections of the Caltrans highway system, there had been incidents of surface deficiencies. Baker believed that these deficiencies were attributable to mix design decisions over which he had no control. Hence, he welcomed the opportunity to make his own decisions on mix designs to meet performance criteria.

Baker, therefore, retained a consultant, B. A. Vallerga, Inc., to carry out a comprehensive characterization and design study of asphalt concrete mixes, using his Fawndale quarry aggregate source with the two binders specified for the Sims Project: a PBA-6 binder meeting the Pacific Coast User-Producer Performance Based Asphalt (PBA) specification and an asphalt rubber (AR) binder consisting of an 80:20 blend of AR-4000 asphalt and a replasticized form of granulated rubber from tires. A program of testing and evaluation of mixes, using the methods and procedures developed at the University of California, Berkeley, under Strategic Highway Research Program (SHRP) Contract A-003A, was recommended to conduct the characterization and design study of the two asphalt concrete mixes.

The characterization and design study clearly indicated that mixes of 100 percent crushed Fawndale quarry aggregate with either the PBA-6 or the AR binder would produce asphalt concrete pavements capable of meeting the performance criteria. This was determined by a program of testing and analysis based on the test methods and procedures developed under SHRP Contract A-003A at the University of California, Berkeley, and Oregon State University.

Details of the SHRP test methods and procedures used; data generated and analytical methods used; and a detailed account of findings, conclusions, and recommendations from this study are set forth in another paper (*2*). Laboratory test results on the asphalt concrete mix design developed indicated that all performance criteria would be fully and reliably met to a high level of certainty within the 5-year warranty period and over the full 10-year life for which Caltrans engineers designed the project.

Impact of Warrantied Pavements on Pavement Management Systems

There remains the intriguing question about how the design and construction of warrantied asphalt pavements will affect pavement management systems. An excellent synthesis on the use of road construction warranties in Europe and the United States has been published by the Transportation Research Board (*3*). One could conclude that the impact would be beneficial to both the operating agency and the public user of pavement facilities.

The operating agency would undoubtedly benefit in a number of ways:

- Reduced costs attributable to early pavement maintenance and repairs;
- Increased safety to maintenance personnel;
- Improved estimates of performance projections and life-cycle costing because of closer attention to performance factors by both agency and contractor personnel; and
- A better understanding of how a pavement system functions and how it responds to the destructive effects of traffic loadings and surrounding environmental conditions.

From the user's viewpoint, a pavement designed and constructed under warranty should result in these benefits:

- Reduced costs in vehicle operation and maintenance;
- Fewer pavement-related traffic delays, which can be quite costly to commercial enterprises and annoying to commuters and the traveling public;
- More driver comfort on smoother, bump-free pavement surfaces; and
- Less chance of costly collisions and injuries attributable to pavement defects.

Although there may be a limit to what benefits can be attained by either the agency or the user, better pavement performance gained through the use of warrantied pavements, as well as better and more reliable pavement management systems, should result in significant efficiencies in construction and travel costs, along with greater satisfaction to the driving public.

References

1. *Special Provisions for Construction on State Highway in Shasta County near Castella, District 02, Route 5.* Contract 02-260404. California Department of Transportation, April 1993.
2. Harvey, J., B. A. Vallerga, and C. L. Monismith. Mix Design Methodology for a Warrantied Pavement—A Case Study. Presented at the 74th Annual Meeting of the Transportation Research Board, Washington, D.C., 1995.
3. *NCHRP Synthesis of Highway Practice 195: Use of Warranties in Road Construction.* TRB, National Research Council, Washington, D.C., 1991.

WORKSHOP SESSION 19

Performance Prediction

Gilbert Y. Baladi (Coleader), *Michigan State University*
Kenneth W. Fults (Coleader), *Texas Department of Transportation*

Various definitions of pavement management and pavement management systems (PMSs) exist throughout the literature. None of these definitions, however, addresses the real process or the main purpose of a PMS, which is to provide its users with opportunities to learn from their successes and failures. The PMS process is a continuing education process whereby users continue to calibrate and sharpen their tools to improve efficiency and productivity. In this context, PMS issues, such as implementation, data collection, pavement performance models, and decisions, become learning issues.

A major PMS learning tool is the frequent evaluation of pavement conditions. The evaluation of a pavement section may involve the appraisal of its functional, safety, and structural conditions. Historical pavement condition data typically are used to assess pavement performance over time. However, the term "pavement performance" usually is defined as how well a pavement section serves the user over time. This definition has led some engineers and highway agencies to use pavement ride quality as the only or as the major attribute of pavement performance. Other engineers and highway agencies believe that pavement performance should include pavement distress, structural capacity, and safety.

The performance of a pavement section over time can be divided into three levels: functional, structural, and safety. For example, the ride quality (functional performance) of a smooth but polished aggregate road can be superior, whereas its safety performance is poor. Likewise, a newly constructed pavement can have a poor ride quality, whereas its structural capacity is very sound. In general, the structural distress (structural capacity) of pavement section also will affect its functional and safety performance. But a functional or safety distress may not affect the structural capacity of a pavement. Hence, pavement performance models that are based mainly on ride quality may have limited applications.

Session 19 of the conference, the Pavement Performance Workshop, was designed to address pavement performance issues. The workshop was divided into a paper presentation session and a discussion of issues related to pavement performance.

Paper Presentations

During the paper presentations, seven speakers addressed various pavement performance issues. Kenneth Fults and Gilbert Baladi moderated the session. The titles and highlights of the presentations and the names of the presenters are given in Table 1.

Discussion

After the papers were presented, workshop participants were divided into four groups. Each group discussed a set of questions related to different issues of pavement performance:

- Pavement performance prediction models (Group 1),
- Individualized pavement distress indices (Group 2),
- Combined pavement distress indices (Group 3), and
- Remaining service life (Group 4).

At the end of the discussion period, each group leader presented the consensus of his group (Tables 2–5).

TABLE 1 Presentation Session

PRESENTER	TITLE OF PRESENTATION	HIGHLIGHTS
Rick Deighton, Deighton Associates, Toronto, Canada	Purposes of Condition Indices	Condition indices can be used to trigger treatments, analyze costs, and measure effectiveness of rehabilitation activities
Bryan Stampley, Texas DOT	Combined Indices	Combined pavement condition indices must be based on index definition. Indices must be verbal or numerical on the basis of needs. Index must be either functional or structural
Fred Hugo, South Africa	A Systematic Approach to Pavement Performance Prediction Using Accelerated Pavement Testing	Pavement condition data from accelerated pavement testing must be integrated with long-term pavement performance (LTPP) data of in-service roads. The data can be used to differentiate between environmental and traffic damage
Newt Jackson, Consultant	Evolution of Condition Indices over Time in Washington State	Methods for the calculation of pavement condition indices must be calibrated as one learns from the system. Jackson showed the differences between the 1965 and 1963 distress indices in Washington State
Brent Rauhut, Rauhut Engineering	Pavement Distress Models Developed for LTPP Data	The presentation addressed a summary of the SHRP data analysis, the development of various distress models, and the applications of neural networks
Tom White, Purdue University	Pavement Management and Mechanistic Analysis	Three types of performance analysis were addressed: relative, statistical, and mechanistic. It was shown that the 3-D finite element analysis method produces more accurate and balanced results
Gilbert Baladi, Michigan State University	Remaining Service Life	The remaining service life (RSL) is the optimum condition index. The calculation of RSL requires distress data collection and, for each type of distress, the establishment of an engineering threshold value. The RSL can be used at the network and project levels and by engineers, managers, and legislators. The RSL is a self-calibrating scale

TABLE 2 Pavement Performance Prediction Models (Group 1), Questions and Group Consensus

QUESTION	GROUP CONSENSUS
Do we need pavement performance prediction models?	Yes
Can we construct a systematic and comprehensive PMS without pavement performance prediction models?	No
Should we use prediction models in a PMS?	Yes
Should we use pavement performance prediction models or pavement deterioration models?	Pavement performance is a function of ride; pavement deterioration is a function of distress
What are the roles of pavement performance prediction models in the pavement design process?	Design can influence performance. Also performance (e.g., rut fatigue, etc.) can influence design
Is it possible for a pavement performance prediction model to be more accurate than the historical distress data collected by the highway agency?	Yes
How often should one calibrate the pavement performance prediction models?	Once a year, and for different segments of the network
Can accelerated pavement testing technology, such as the LMS, be used to develop performance prediction models?	For high-volume roads, other supplemented data such as LTPP should be used
How many performance prediction models should be developed and implemented in a PMS?	Family of curves (e.g., structural—cracking and deformation, functional—roughness, etc.)

TABLE 3 Individualized Pavement Distress Indices (Group 2), Questions and Group Consensus

QUESTION	GROUP CONSENSUS
What are the benefits of calculating pavement distress indices?	To establish limits and comparisons
What rating scales should be used for the various pavement distress indices?	It depends on the users. Training and continuity should be considered
Should the type of rating scale or the threshold value along the rating scale affect the number of pavement sections that are in need of repair/action?	Policy decision by users
Should the calculation of pavement distress indices be based on sound engineering criteria?	Yes, as well as on economic and user needs
What engineering criteria affect the calculation of pavement distress indices?	Relationships to failure criteria, weighing method, and time of use
How can we develop engineering criteria for the calculation of pavement distress indices?	By using models and calibrating scales
Should we use the pavement distress indices in pavement performance prediction models?	Yes
How many pavement distress indices should be calculated and examined?	Many, but use them for trigger values, cost estimation, and reevaluation

TABLE 4 Combined Pavement Distress Indices (Group 3), Questions and Group Consensus

QUESTION	GROUP CONSENSUS
Do we need to calculate combined pavement distress indices?	Network level, yes; project level, no
What uses can be made of the combined pavement distress indices?	To categorize pavements into overall groups for ranking purposes
Can combined pavement distress indices be used in a pavement performance prediction model, or is it preferable to differentiate between environmental and traffic damage?	Yes
If needed, is it feasible to use accelerated pavement testing for differentiating between environmental and traffic damage?	Yes, but this is more of a research activity
What are the impacts of the combined pavement distress index on the decision-making process?	At the network level, it keeps things simple
Is it possible to use combined pavement distress indices to enhance engineering communication?	No, you lose too much detail
Is it possible to use combined pavement distress indices to enhance communication with upper management and legislators?	Yes
Is it possible to use combined pavement distress indices to determine the required rehabilitation alternative?	Absolutely not
Is it possible to use combined pavement distress indices to rank and optimize the various pavement sections within a network?	Ranking, yes. Optimization is very difficult

TABLE 5 Remaining Service Life (Group 4), Questions and Group Consensus

QUESTION	GROUP CONSENSUS
Do we need engineering threshold values?	Yes
What are the uses of engineering threshold values?	To develop RSL and determine treatment strategy
Should we predict the RSL or simply calculate it from the given distress data?	Calculate and modify it to reflect reality
Should accelerated pavement testing technology be used to assess the rate of deterioration of a pavement section and to estimate its RSL?	Yes, qualified by rate of loading, etc.
Can the RSL be developed and used as a prediction model?	Yes
Is it possible to use the RSL of pavements to express the benefits of rehabilitation actions?	Yes, to define improvements in condition index
Can we use the RSL to enhance communication between engineers and upper management and legislators?	Yes
How can we calibrate the engineering criteria and threshold values used in the calculation of the RSL?	By using cost studies
Is it possible for the RSL of a pavement section to be a nonlinear function of time?	Yes

WORKSHOP SESSION 23

Defining an Appropriate System

David T. Anderson (Leader), *Roads Corporation, Victoria, Australia*

The purpose of the workshop was to examine the various factors that are important to take into account in selecting, developing, and maintaining a pavement management system (PMS) to ensure that an agency gains maximum benefit from its investment. The workshop participants decided that the most important factors to consider when initially selecting a system were the following:

- The types of systems available and how closely they match the agency's needs and goals. To this end it is important to spend sufficient time defining these needs and goals before proceeding.
- The outputs required from the system to report effectively to budget decision makers and the style and scope of information they need to make their decisions.
- The type of data available for pavement management and the design of any data bases that already exist. These data and data bases are extremely valuable and therefore should influence the choice of analysis system.
- Compatibility with other management systems that already exist within the organization to facilitate integration in the short or long term.
- A potential system's ability to take into account user costs or at least the pavement condition factors that in a particular network will have the greatest influence on user costs.

The participants concluded that unless an agency decides what the scope of a system ought to be, there is a risk of selecting and developing a black box that in the long run will not produce credible results relevant to the needs of the senior management or budget decision makers.

System Development Factors

Several factors were considered important in developing an existing PMS system. Among these is maintaining the support of the organization's leadership by ensuring that changes do not overly complicate the existing system and by retaining the system's flexibility. For example, the agency may wish to change the way it manages a particular class of road or change the condition measures that are to be used for programming maintenance or rehabilitation works. It is therefore necessary to understand how the organization wishes to make technical decisions concerning when to intervene in the management of a particular pavement—for example, what condition justifies resurfacing. A system must remain flexible enough to cater to such changes.

Ensuring that the sophistication or complexity of the system does not surpass the ability of the staff using it is also important, so that the organization retains its understanding of how the system works and decision makers can maximize its benefits.

The quantity and quality of data required to manage pavements should be considered. It is too easy to request the collection of all imaginable data when in fact only a portion of the information will be used for management decisions. Likewise, it is easy to specify unreasonable levels of data accuracy, which will not result in better decisions being made. The workshop participants recognized that data collection costs could be high and wasteful if these factors were not managed properly.

The most effective possible styles of presenting results should be identified to facilitate decision making. Recent developments in graphic and other types of presentation packages for computers have enabled pavement managers and engineers to produce outputs in various forms. It is probably not necessary for the PMS itself to produce this variety, but only to produce results in a form that can be manipulated by a standard presentation package.

In summary, development of the system must be entirely compatible with the decision-making environment of the organization from the point of view of staff skills, relevant data types, quantity, quality, and the required reporting style.

System Maintenance Factors

Regular review of the PMS network's maintenance standards is important to its continued performance. Maintenance standards should also be updated in the PMS analysis or optimization process.

Feedback from the PMS users and decision makers is also vital to ensuring that the PMS is satisfying their requirements. The benefits of the operation and use of the PMS should be determined to evaluate the worth of investment in PMS.

Participants noted that the conference had not contained much information about the derived benefits of pavement management systems, even though this subject is of fundamental importance. The workshop participants suggested that the evaluation of benefits should be one of the major themes of a future conference.

Conference Summary

William D. O. Paterson, *World Bank*
Billy G. Connor, *Alaska Department of Transportation and Public Facilities*

The Third International Conference on Managing Pavements was held in San Antonio, Texas, May 22–26, 1994. The conference drew 540 delegates from 41 countries. Sixty-five papers were presented covering six conference themes:

- Appropriate systems,
- Institutional issues,
- Analytical issues,
- Implementation issues,
- Managing information, and
- New frontiers.

Appropriate Systems

A pavement management system (PMS) must be carefully selected to meet agency needs. All too often a black box system is selected without regard to agency goals, needs, or resources. Such systems usually lead to failure.

The first step in selecting a PMS is to establish the goals and needs of the agency by considering the decision-making process, staff size and abilities, data requirements, network size and complexity, and how often the system will be used.

The conference highlighted several guidelines for choosing or developing a PMS:

- Keep the system as simple as practical.
- Build the system in a modular form so that new modules can be added and old ones can be easily changed.
- Collect only data that will influence the decision-making process.
- Tailor outputs to the user. If multiple output formats are required, use them.
- Carefully document the system. Turnover inevitably affects all agencies.

Selecting the appropriate PMS is a difficult process for any agency. Typically those involved in selecting the system must be educated about the variety of systems available. Each system has strengths and weaknesses. The selection team must carefully determine which system best meets the agency's needs.

Although many systems are available, it is doubtful that any of them will exactly fit the needs of the agency. If the system cannot be modified to meet agency needs, it is probably not the right system. First, it is difficult to make radical changes in the way the agency does business. A system that requires sweeping changes will fail. Second, agency needs will change. If the PMS cannot accommodate such changes, it will cease to be used. Finally, as the agency becomes more familiar with the PMS, the agency will likely ask more of the system. Therefore, any PMS must be able to grow with the agency.

As the system is developed, users at all levels must be kept informed. It is important for the agency to show users what the system can do and to ask whether the information provided by the PMS is appropriate for their needs. If it is not, changes will be necessary.

The agency must make sure that the complexity of the system does not exceed users' skills. Too often, a PMS fails because no one understands how to run it. An organization with high turnover, for example, should consider a system that is easily learned. If the system is used only once a year, it is important to make sure that the system is easily remembered.

The proceedings of this conference offer considerable guidance in selecting the PMS appropriate for national, state, and local agencies. The advice offered in these proceedings is based on many years of experience by others who have or are implementing a PMS. The experiences offered in these proceedings are invaluable to anyone involved with PMSs.

Institutional Issues

Although PMSs have been around for 20 years, the technology is still not fully implemented. Many agencies have PMSs, but their decision-making processes may not have changed. The reasons are rarely technical. Three types of barriers exist: people, organizational, and the PMS itself.

People Barriers

People barriers stem from turf protection, fear of exposure, and ownership, resistance to change.

Turf Protection

Many people see a PMS as a threat to their authority. If a PMS is implemented, they believe that it will remove their ability to make independent decisions. Sometimes those who most fear a PMS are those who have information tucked away in a file that no one else sees. These individuals may release information only to support their positions. A PMS would make this information available to anyone who needs it.

Many organizations make funding decisions based on consensus management. Those involved in this process may see a PMS as a threat to their participation in the funding process. There have been instances in which a particularly influential person has lost because a PMS provided information that countered his or her view. Such losses can mean fewer projects in such individuals' districts.

Ownership

"Not invented here" is a common excuse for not implementing a PMS. People may not be comfortable with something they did not have a hand in developing or at least selecting. Lack of understanding may be the key reason for not accepting systems developed externally.

Two methods of overcoming ownership problems are commonly used. The first is to develop the PMS in-house even though the cost may be greater. The development process can provide an understanding and acceptance of a PMS. The cost of developing a PMS can be reduced by reviewing the many systems already in place and borrowing whenever possible. The second method is to carefully study available systems and select the one that best fits the agency's needs. Modification of such a system can result in ownership of the system.

Often, lack of ownership results because the PMS does not present information in a format normally used by decision makers. Decision makers often are not concerned about the detailed processes used in a PMS. Instead they concern themselves with the information it provides. Therefore, a third method is to revise the PMS format to look like the existing format.

These proceedings contain several examples of how agencies have overcome PMS resistance due to lack of ownership.

Fear of Exposure

Agency personnel may fear that a PMS will expose bad decisions. Although this can happen, it must be recognized that such decisions usually are the result of poor information. Further, if people recognize that a past decision was not the best decision, they have gained knowledge. That knowledge, if properly used, will help people avoid future mistakes.

People also may be afraid that a PMS will cause them to make bad or unpopular decisions. Again, bad decisions are the result of lack of information. A PMS provides that information. It is likely that some decisions will be unpopular; however, through education of the public using the information provided by a PMS, this can be overcome. If not, perhaps the public has a different agenda. Here, the PMS must be altered to fit the desires and needs of the public.

Resistance to Change

Many people resist change. These people simply may not wish to take the time to reshape their thinking or revise their work habits. This barrier is possibly the most difficult to overcome.

Change is necessary to counteract tightening of resources. How can we convince others to accept change? The answer lies in the reasons why people resist change in the first place.

Many people view change as a threat. The best way to overcome this is to allow them to direct the change, to educate them, and to allow them to be part of the process.

Change often means a change in work habits. It is important to avoid rapid large-scale changes. Changes should be made so that the work force can accept them. People must be convinced that the goal is worth the struggle.

Organizational Barriers

Organizational barriers include size, structure, past management, stability, the planning horizon, project constraints, resources, personnel turnover, and funding availability.

Implementation of a PMS can be blocked by one person in a small organization. Larger organizations usually have means to bypass one person. However, lines of communication and policies in larger organizations may block implementation. Such momentum in larger organizations is often very difficult to overcome.

The structure of an organization may not be conducive to implementation of any system that crosses organizational boundaries. The lines of authority in small organizations are usually less clear than those of larger organizations. A PMS affects planning, design, construction, and maintenance. Communication across these boundaries is often difficult. Many organizations have successfully used a PMS to establish these lines of communication.

Most organizations have well-established management and decision-making procedures. Whether formal or informal, these procedures can be difficult to change. For example, many organizations use a consensus method to select projects. Using this decision-making process, organization decision makers simply develop a program by developing a consensus. Often the most persuasive people get the most money. A PMS, to many, threatens this approach. The more powerful members of a decision-making team may fear that they will lose some of their power.

Most organizations undergo constant changes in policy and personnel. A rigid PMS rarely fits into such organizations. Public priorities change, and personnel turnover is a reality.

The planning horizon varies from 1 year for local governments to 20 years for regional, state, and federal governments. Pavement management by its very nature looks into the future to predict pavement performance. Most local governments are not used to budgeting several years in advance.

All projects have constraints, including timing, funding availability, compatibility and coordination with other projects, and public acceptance. A PMS must handle these constraints.

System Barriers

The PMS itself can be a barrier. If a system already is in place, many people will fight changes to the existing system.

Analytical Issues

The analytical aspects of a pavement management model are the heart of the system, on which much of its credibility rests. The ability of the internal model to forecast deterioration and the consequences of alternative maintenance strategies and to outline an expenditure program meeting some optimization criterion depends on the conceptual structure and the validity of many individual relationships. In these respects, the various PMS models presented at the conference differ markedly, creating an area of limited consensus. One interesting suggestion made was to compare PMS model outputs for a common set of pavements. Papers and workshops were organized around the subthemes of performance prediction, analysis, optimization, and road user costs.

Performance Prediction

The five papers on performance prediction (Session 4) illustrate differences in the approach to modeling, a number of dominating issues of data quality and processing difficulties, and some welcome findings on the modeling of maintenance effects—a previously neglected aspect.

For the modeling approach, most authors to model distress modes separately, confirming difficulties in modeling composite indicators. Workshop participants commented that composite indices are better used for delimiting sections and for reporting than for modeling. Three papers adopted a deterministic empirical approach. The adoption of a structured empirical interactive model, which models changes as a function of structural, traffic, time, and condition parameters, was successful in a study in India on overcoming data variability difficulties (Sood et al., vol. 1, pp. 47–54). This is another example of the transferability of the model structure from World Bank studies.

Difficulties in the modeling process were described in a Minnesota study (Lukanen and Han, vol. 1, pp. 63–73). The difficulties were treated by carefully grouping into data families and ensuring that survivor pavements were not excluded. A validation and verification approach described by Jansen and Schmidt (vol. 1, pp. 74–84) used performance monitoring data to improve an empirical roughness model and a mechanistic structural model. Workshop participants suggested the use of accelerated pavement testing for developing models when environmental influences are incorporated. Validation under long-term monitoring, however, was still advised to confirm the time-related effects, which can be significant.

An application of artificial neural networks (Attoh-Okine, vol. 1, pp. 55–62) shows promise as a means of basing predictions on available historical data and learning in real time. Some progress on mechanistic models incorporating a stochastic decision tree is reported by Chua et al. (vol. 1, pp. 85–94).

Data quality and processing methods are dominant issues. Data variability hides relevant trends and makes it difficult to determine factor effects beyond simple time-based regression models. Both the Sood et al. and Lukanen and Han studies emphasize the need for more accurate measurements, such as calibrated roughness meters or profilometers for roughness. Censorship of data, which applies to the omission of survivor pavements from an analysis of pavement life, introduces significant bias, and steps are needed to avoid this. Statistical techniques are available and have been applied to pavement modeling. Data on maintenance inputs need to be collected regularly for performance analysis to make sense. Researchers should make concerted efforts to use standardized units, preferably international units, when modeling and setting up data bases so that the results and data can be evaluated elsewhere and a much stronger basis for models and verification can be built. At least the conversions should be determined and presented in published papers.

The findings advance our knowledge on prediction modestly. The most important findings are on maintenance effects, showing that a pavement's roughness after overlay depends not on thickness but on its previous condition (the Lukanen and Han and Jansen and Schmidt studies). This finding is not likely to be valid if the existing profile has substantial amplitudes in which a 25-mm (1-in.) thickness is inadequate. On roughness, the Sood et al. model confirms the transferability of the multiple interaction model and the significant contributions of distress and nontraffic (time-based) effects. The Sood et al. time effects are rather large at 9 percent per year, probably because of the local construction techniques, and the Danish effect is about 4 percent annually. Such aspects can be compared across studies to identify environmental and other effects. A structural condition model shows that overlay thickness is related to a pavement's residual life and the design period. A considerable amount of field research and modeling on maintenance effects still must be conducted so that our combined level of confidence in predicting maintenance effects can improve. These effects have a major impact on the benefits realized from a maintenance strategy.

Analysis

Regarding analysis methods, the development of the United Kingdom PMS (Phillips, vol. 1, pp. 227–236), which will apply to all paved areas in urban and rural jurisdictions, has interesting features. It is a third-generation system, optimizing multiple options for the entire network to maximize economic benefit. The network analysis and creation of a work program (scheme) is done in two passes: one automatic and one interactive. The automatic pass segments the network into areas of uniform defectiveness and identifies treatment by the domain of one or more current defects. Priorities are determined by condition indices relative to threshold values. The interactive pass allows the maintenance engineer/planner to review, refine, and build up the program interactively, using similar consistent criteria. Projections of future conditions are made via a generalized S-curve relationship, which is calibrated to historical data for individual sections and defects. Final priorities are set on the basis of savings in total costs and of savings to agency and users, including delay costs, simplified to first-year benefits and an incremental benefit-cost ratio.

Two papers deal with the application of the Highway Design and Maintenance Standards (HDM-III) model, which applies a yearly technical and economic evaluation to pavement management. In a study of roads in Bavaria, Sršen (vol. 1, pp. 246–256) found a prevalence of rehabilitation strategies. Through a sensitivity analysis, he shows that the roughness and traffic volume variables dominate the outcome because user costs comprise 94 percent of the total costs and lessen the impact of maintenance costs on the choice of optimum strategy. In a pilot PMS implementation in the Philippines using HDM in a geographic information system framework, Howard et al. (vol. 1, pp. 267–277) use a link-aggregation approach to network analysis, identifying 488 categories of pavement type, condition, traffic, and quality. Innovations include a special calibration of the model for concrete pavements and an extension of the optimization module to 500 links.

Assaf and Haas (vol. 1, pp. 257–266) present an interesting tool, MAREE, capable of evaluating past maintenance and rehabilitation strategies, identifying relevant criteria, and verifying the performance of the strategies. This provides a useful way of characterizing the success and effectiveness of past and present policies. Shahin et al. (vol. 1, pp. 237–245) show the incorporation of criteria for maintenance and rehabilitation categories into MicroPaver and a financial analysis of maintenance cost savings.

Optimization

Thompson (vol. 2, pp. 184–189) outlines how optimization techniques can be incorporated effectively into agency policy making if such techniques are made more understandable and responsive to agency objectives. Such objectives might include preserving pavements, reducing user discomfort, and reducing citizen complaints. The techniques should be modular, fast and easy to use so that they respond to what-if analyses, and flexible enough to accommodate policy and objective modifications and should incorporate consistent methodology across modules and correct methodology for credibility. The development team should include professionals from each discipline, such as engineering staff to review engineering validity and planning and budgeting staff to guide management language and legislative strategy.

Building such practical aspects into the system automatically rather than interactively with the user is addressed by Wang et al. (vol. 2, pp. 173–183). Noting that the "true optimum" may not be the best possible alternative from a network optimization system (NOS), they introduce a knowledge-based expert system to apply engineering logic to the demarcation of sections and treatments.

The effects of various objective functions are studied in three papers. Smadi and Maze (vol. 2, pp.195–204) test the objective of minimizing cost for prescribed performance standards for consistency with the Iowa Department of Transportation engineering strategy. Alviti et al. (vol. 2, pp. 190–194) modify the Alaskan NOS to address the question "What maximum performance standards can be maintained for a fixed budget?" Butt et al. (vol. 2, pp. 159–172) find that optimizing the benefit-cost ratio results in a lower budget, but optimizing the incremental benefit-cost ratio results in higher performance standards. Defining "benefit" in terms of physical condition (pavement condition index [PCI] time), not economic value, is misleading, and the original term "effectiveness" should be used.

The comparison of these three objective functions is best viewed in an economic context, which also ties in these papers with the HDM examples of the "Analysis" theme. Figure 1 compares the economic net present value (NPV) of alternative strategies with the annualized agency cost or budget. The NPV is the savings in total costs to agencies and road users over the whole life cycle, expressed in present values. The curves show the benefits associated with raising the performance standards of various strategies, and the envelope of all these is the maximum benefit obtainable for any agency budget. The maximum benefit-cost ratio naturally occurs at a lower agency cost than the maximum net benefit (NPV), and the maximum incremental benefit-cost ratio can occur anywhere below the efficiency frontier. Maximizing performance standards for a fixed budget is essentially the same as maximizing the economic benefit for a constrained budget; therefore, the former is the best of the three optimization objectives.

Road User Costs Versus Agency Costs

There are two schools of thought on the consideration of road user costs (RUCs) in determining road expenditure strategies. On the one hand, the acceptance of RUCs as an integral

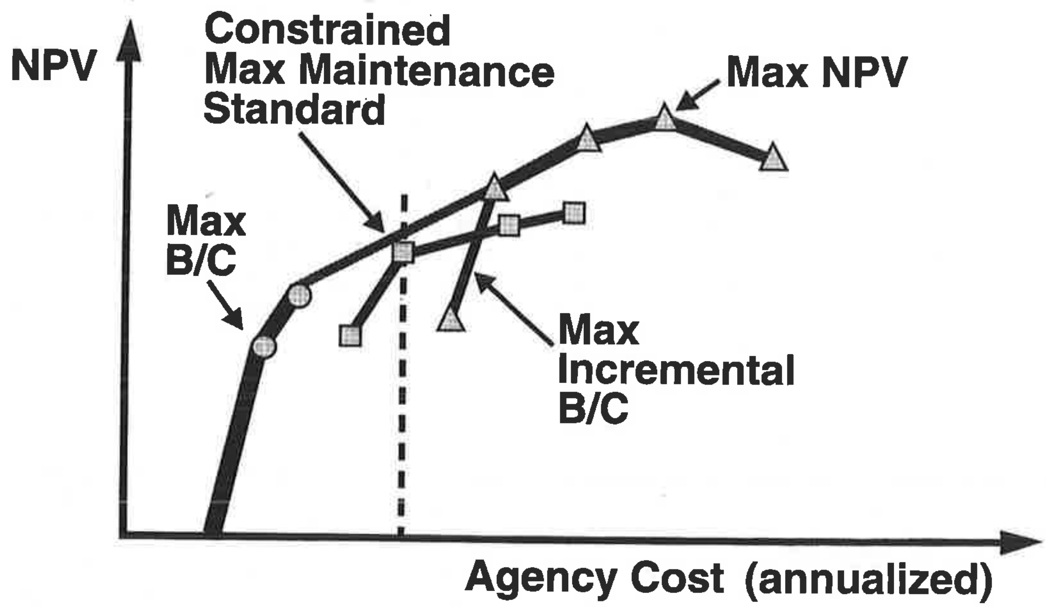


FIGURE 1 The economic efficiency frontier approach to optimization.

element of economic analysis is more evident (*a*) in countries outside the United States, especially where agency reform has followed commercial business practices and emphasis has been placed on getting return on investment, and (*b*) in developing countries through the requirements of international lending agencies. On the other hand, opinions at the practitioner level in the United States are still divided on the issue, as evidenced by the differing verdicts of workshop juries (Figure 1). The main observations follow:

1. There was consensus on the value and relevance of RUCs for policy and planning purposes (i.e., strategic and network-level analyses), but not for project-level applications.
2. There was concern that RUCs will overwhelm agency costs and lead to unrealistic maintenance and rehabilitation strategies and an unfair allocation of funds between the high-volume urban and low-volume rural areas.
3. There was concern that agency costs are "hard" and easily quantified, but that RUCs are "soft" and many benefits are intangible and difficult to quantify.
4. Concern was expressed about the uncertainty and validity of condition effects on vehicle operating costs (VOCs). (It was expressed, however, that the existing relationships are as reliable as pavement design life predictions, which range by a factor of 3 at high levels of confidence and which practitioners accept readily.)

The regular users of VOCs have resolved many of these issues and place appropriate constraints where required. It was noted that in practice the rehabilitation intervention levels resulting from the use of VOCs are usually close to or slightly higher than typical U.S. ride comfort requirements. There is widespread recognition of a need for a new, careful study of VOC savings for modern vehicles on even, low-roughness pavements, where some evidence indicates that these may be negligible at roughness levels less than 3 m/km international roughness index (IRI) (200 in./mi IRI), and that this should be a priority for new research funding and international cooperative study.

Implementation Issues

Barriers to PMS implementation can be overcome with proper planning. Successful PMS implementations have been accomplished through steering committees. These committees consist of all important players in an organization. Through consensus-building techniques, committee members were educated and given pride of authorship in the system. In doing so, most implementation barriers fell.

It is important to ensure that information is provided in the proper format. Nontechnical people may have little tolerance for technical jargon. Because governing bodies want to know a budget and what that budget will buy, information provided should reflect the needs of the audience.

For example, when presenting the results of a PMS to a city council, telling council members that reducing the budget by 10 percent will cause the present serviceability index to drop from 2.5 to 2.0 in 3 years may not be helpful. Council members may have no idea what that means. It is better to tell them that the number of potholes will increase by 30 percent, that it will take them more time to get to work, and that the number of complaints will probably increase by 10 percent. Politicians understand responding to complaints.

Show beneficial results immediately. It is infinitely better to sell the results of PMS rather than the PMS itself. Frequently, decision makers do not care to know the details of a PMS. They care only that the budget is defendable and realistic.

It is important to ensure that the system is compatible with the organization. Too often we forget that a PMS is a tool to help us make good decisions.

An organization cannot be driven by a PMS. Because an organization will change, it is crucial to build in change. The best way to ensure flexibility to accommodate change is to build a PMS in interconnected blocks that can be modified easily.

In addition, complexity should be minimized. Complex systems are difficult to understand. Further, they require heavy funding to support. A system that is too complex for the job will certainly fail.

Finally, although technological advances in PMS will come, the barriers facing PMS will continue to block implementation of these advances. We as practitioners of PMS technology, must become skilled at dealing with these issues. This may require seeking help from other disciplines.

Managing Information

Much of the credibility of pavement management rests on the reliability of the data on the condition of the road system that is analyzed and on the usefulness of the information provided by the system to managers, owners, and users of the road system. Good information may not guarantee sound management, but the lack of good information makes it very difficult to make sound decisions. This theme was organized around three objectives: better management of data, better monitoring procedures, and better information on road system performance.

Data Management

There were six papers on this subject and a major focus on standardization in the opening session. Pavement condition data and surface distress measurement were addressed in papers by Cenek et al. (vol. 2, pp. 265–278), Livneh (vol. 2, pp. 279–289), and Prakash et al. (vol. 2, pp. 290–301). These provide interesting data on the reliability of manual surface distress surveys and comparisons between different methods. The survey components include repeatability (precision), reproducibility (bias between surveyors and surveys), and bias with respect to a true or reference value. Livneh compares a new Israeli drive-over method with a similar Washington Department of Transportation method and detailed PCI and PCR methods in a series of studies. The new drive-over method was shown to have similar reliability to the detailed methods, while being several times faster. Prakash, studying the Canadian PCI and distress index, found that the experience of the raters did not affect their precision, but that inexperienced raters and one region showed biases. Certain distresses were rated more

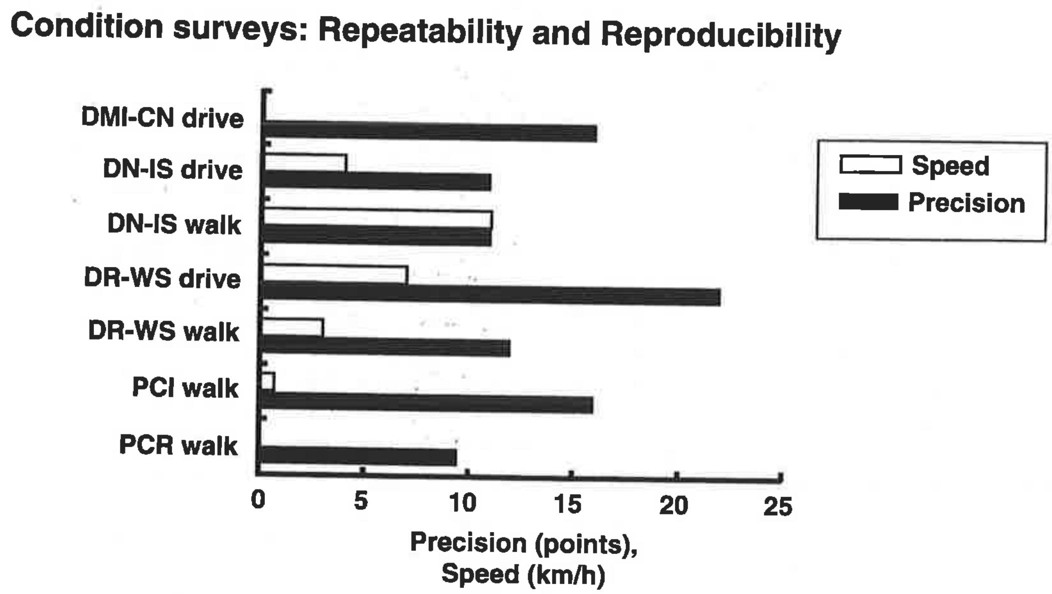


FIGURE 2 Comparison of data quality from pavement distress survey methods [derived from Livneh (vol. 2, pp. 279–289)].

consistently than others. The impact of training in reducing bias was clear. The precisions of the various methods on a 100-point scale are compared in Figure 2, and there are obvious trade-offs to be made in relation to survey speed. During discussion, Irwin warned that a composite distress number obscures the individual distress modes and thus has lower utility in the decision analysis model (Figure 2).

Quality assurance (QA) procedures developed during the Strategic Highway Research Program (SHRP) for roughness (Henderson et al., vol. 2, pp. 302–314) and FWD deflection (Irwin et al., vol. 2, pp. 315–325) measurements have potential applications by highway agencies elsewhere. The roughness QA, which applies to inertial, noncontact profilometers, requires (*a*) tight data acceptance criteria, (*b*) data record completeness, (*c*) device verification with a reference static profile device, and (*d*) verification for the reference device. The primary roughness reference for acceptance is the IRI of each wheel track; other numerics are calculated for information. The FWD QA procedures aim to control the systematic error (bias) of deflection readings between testing devices and testing over time. The examples of the FWD procedures show adjustments that are typically less than 0.5 percent when the procedures are followed.

The transition from a manual/mechanical combination of methods to automated multifunction methods was the subject of a New Zealand study (Cenek et al., vol. 2, pp. 265–278). The study showed a major difference in rut depth data, due in part to a difference of definition between a straight-edge model and a wire-chord model. There also were differences between skid resistance and texture measurements. Fortunately these will be resolved through the upcoming international friction index. The largest difference, however, related to the sampling process. The study showed clearly that automated outputs that average a measured characteristic over a long section length miss vital information on the incidence of subsections that fail prevailing threshold criteria. Current Swedish practice is to provide both short- (e.g., 20-m) and long-length (e.g., 400-m) outputs, which permits the supplementing of long-section outputs with statistical information on distribution or incidence-type data without requiring the storage of the huge volume of short-section data.

Perhaps one of the most important messages on managing information is the value of data standards. It echoes the strong plea by FHWA's Dean Carlson during the opening session for uniform data collection standards. The topic of data quality points out the need for a standard method to minimize both random and systematic variations. The situation presented by Cenek et al. regarding the transition from an existing condition survey method to an automated method underscores the value of a reference that harmonizes such basic measures as rut depth. The progress made since the identification of IRI has been substantial, by placing worldwide data into a common pot. We need to make concerted efforts to implement these emerging international data standards—the existing IRI and the forthcoming international friction index—and to identify standards for outstanding items such as rut depth and cracking. Then we will be able to broaden our data bases to concentrate on more reliable models and implementation.

Better Monitoring Procedures

Considerable advances in technology are causing dramatic changes in road monitoring procedures. At the last conference in 1987, manual distress surveys, response-meter roughness surveys, and straight-edge rut depth measurements were the common modes of surveying. Now, noncontact surveying of longitudinal and transverse profile, texture measurement, and image capture are possible at traffic speeds with automated road monitoring equipment that has moved past the prototype and special survey status into a competitive service industry. Such service is available from a number of suppliers, becoming affordable and attractive in terms of safety of surveying personnel.

Other changes are as significant though perhaps more subtle. A more rational, critical approach is being taken by some toward the information required and data that need to be collected. When technology makes it feasible to collect so much data, it can become tempting to demand more data than are useful or needed. In designing the monitoring system for the autobahn in Germany, the approach was to select data items for measurement on the basis of their problem-solving capacity (Burger et al., vol. 1, pp. 150–160). The French National Highway Authority has codified six levels of pavement condition survey, M1 to M6. M1, M2, and M3 are detailed, project-level, and network-level surveys, respectively. M4 to M6 are special surveys involving, for example, the GERPHO image capturing device (Lepert et al., vol. 1, pp. 161–169). The M3 survey described in the paper has limited recorded surface distress to just five parameters and records them through a simple keyboard that allows collection at slow drive-over speed—in this case, using a system that was affordable and effective.

Some profile sensing devices are capable of measuring a wide bandwidth, from macrotexture (0.5 mm) to long waves (100 m), as indicated by the Danish example (Larsen et al., vol. 1, pp. 170–175). The multiple sensing capability for transverse profile is raising the question of how rut depth and transverse profile should be defined. This problem is clearly one that needs to be resolved.

Image capture, image processing, and digital storage are in the process of revolutionizing the collection and definition of pavement condition and road inventory data. There are new opportunities to redefine some fundamental measures, such as cracking and other distresses, to take advantage of this technology. High-speed deflection survey capability is also emerging.

Questions about this new technology focused on when it is appropriate to undertake the various surveys with separate devices or to combine most of them with a multifunction device, whether to buy the device or to buy the service of conducting the survey and supplying the data, and how to facilitate the procurement of such services. The option of procuring the service is becoming attractive; several agencies have been doing this. A data supply service relieves the agency of having to own, maintain, and operate an expensive high-technology capital item and having to deal with the concomitant issues of personnel skills and training. A competitive procurement process will ensure that each service contract provides up-to-date technology (a big advantage in an age when technology changes so fast), fair prices, and a stimulus for technology development. Agencies in the United Kingdom, Scandinavia, Eastern Europe, Australasia, and North America have adopted service contracts, and it is being pursued as an attractive option in some developing countries. Such contracts require careful specification of services—the data to be collected, survey scope, and data delivery format—which is another strong incentive for identifying and adopting harmonized standards.

The linkage between pavement management and management of all other elements of the road system is vital. This and the automation of data collection requires improvements in location referencing and a range of software environments for data management and processing. Linear referencing still appears most appropriate for road data, but spatial referencing through the Global Positioning System (GPS) and the use of GIS technology for integrating layers of different infrastructure systems and subsystems is growing rapidly. The advantages are clear in urban areas, for emergency response and safety, and environmental and resource issues. The workshop on the topic indicated that a reference point method was becoming a preferred linear referencing method, but that the key is to have a referencing system that links the different methods in use by various agencies within a jurisdiction.

Better Management Information

Ultimately, roads are being managed on behalf of the road owners—usually government, but sometimes a corporation or franchise. In the past several years, as government departments have come under pressure to be more efficient and as public service reform has placed the provision of roads and road management on a more commercial basis, road managers have been becoming increasingly accountable for their performance. There is now a clear, often mandated, need for understandable relevant information on the performance and condition of the road system to be made available to the owners and users. Road system performance indicators, at a level best termed "system-level" because there is no link identification, are receiving a renewed focus that has special urgency.

In a number of countries where road provision and management have been placed on a commercial basis, including much of Scandinavia, the United Kingdom, New Zealand, and Australia, performance indicators become part of a contract between the road agency and government. They are a means by which an agency is held accountable for the effective and efficient use of public funds. In addition, the direction is clear concerning new requirements for funding allocation by federal and state governments in the United States. This goes beyond the early emphasis on riding quality and bare statistics of road lengths and accidents. It requires new thinking on exactly what we as managers are required to do and what is expected of us.

In Finland, overall performance is being evaluated in an index involving three elements—pavement and traffic conditions, environmental impacts, and an agency's productivity and profitability—with a specified weighting. Each element comprises such components as pavement condition, traffic safety, and winter maintenance effectiveness for pavement and traffic conditions. These components, in turn, are computed from road monitoring data (rut depth, IRI roughness, surface defects, and bearing capacity), and the fraction of the network meeting these criteria form the basis of the performance contract.

Other interesting examples include Hungary, where, in addition to condition and strength indicators, the depreciated asset value as a percentage of the replacement value has been monitored. Other conference papers present information on indices being reported in the new systems in Germany and France and on a study in Qinghai, China. These focus on pavement quality aspects. In the countries where the public sector is being commercialized, efforts to identify relevant and quantifiable measures are serious, and active dialogue is developing. At an international level, the World Bank has identified five perspectives representing various road system stakeholders and is identifying relevant indicators within each; namely, infrastructure provision, user service quality, provision efficiency, sectoral effectiveness, and institutional effectiveness. There is the prospect of some of these becoming new international statistics, and this is an opportunity for dialogue to establish some common threads, if not consensus.

New Frontiers

The contracting of the full range of road work and pavement management services, normally undertaken by a road agency, provoked considerable discussion at the conference and has significant implications as a new frontier for pavement management and managers. Most cases show equivalent or improved work performance and responsiveness under contract. A corresponding improvement in force account (agency) performance in response to the competition is indicated in at least two cases. The experience of cost savings is less clear, with savings ranging from 25 percent down to nil, the savings becoming smaller as an agency responds by improving its efficiency. The definition of pavement condition for end-result specifications of contract maintenance or warranted rehabilitation and for performance-based contracts requires standard definitions and agreed-on methods for quantifying and measuring those parameters. Stated practices varied, but the call for guidance was unanimous.

The contracting of road management services resulted in a more interesting reaction, although the topic was addressed only obliquely. This raises the question of the compatibility of PMSs and under what circumstances the adoption of a standard PMS might be necessary, as found in the New Zealand approach. The issues include the scope of services to be covered; for example, data collection, processing, analysis, and storage. What harmonization would make this viable in the absence of requiring a standard PMS? These are likely to be priority issues at the next conference, by which time there will be many more experiences to compare.

Placing PMSs in the context of other infrastructure management systems is a welcome sign. Hudson and Hudson (vol. 2, pp. 99–112) identify the common linkages not only with other systems for road management, but also for systems for public infrastructure, municipal infrastructure, and unitized facilities. GIS technology, with its powerful capability for handling multiple horizons of data systems, and the introduction of business management and mapping practices in these other areas are intersecting with pavement and bridge management and have the potential for making major advances in all areas. The benefits in communication and coordination in local and regional governments are likely to be substantial.

Concluding Thoughts

Drawing on all these deliberations for the themes of analytical issues, managing information, and new frontiers, the following are five areas on which attention should be focused in the next few years:

Credibility of Models

There is a need to focus modeling efforts on validation and to build the credibility of the forecasting and analytical capabilities of pavement management models. Further improvements in our prediction capabilities depend in large part on our willingness to build on existing strong models and on establishing validity from empirical evidence, refining and strengthening the models where possible. This is particularly needed for maintenance effect models and maintenance treatment performance and requires the use of sound statistical techniques—one reason the tutorial on the subject was so valuable.

Decision Criteria and Objective Functions

Decision criteria and objective functions for optimization need broader and more thorough attention. This includes the introduction of formal economic evaluation principles for monetary and nonmonetary benefits and the critical assessment of the appropriate criteria for strategic, network-, and project-level applications, respectively. This implies a need to formalize the quantification of benefits and a need to fund primary research that quantifies road user costs in high-standard road environments.

Harmonization and Quality Management

In the basic building blocks of management system data and terminology, we are overdue to graduate from scrambling around with many definitions. It is time to adopt available standards and strive to reach consensus on remaining ones (particularly rut depth, transverse profile, cracking, and terminology) so we can concentrate on the product of the system rather than on the process. This way we will improve information quality and open the door to a wealth of shared knowledge and a wider market.

Better Information

We need to focus the information message. Avoiding the seduction of powerful modern technology to collect everything, we need to reduce the information we produce to the essential items that influence the outcome—the product. At the highest level—summary performance indicators—there is a desire and a need to liaise at an international level because many countries are in the process of choosing indicators that seem to be relevant.

System Integration

To succeed in the political process and to function effectively in the institutional environment, pavement management must become integrated within the process of road infrastructure management. The management system framework needs to be applied to all aspects of infrastructure assets in whatever transportation subsector or jurisdiction we happen to be—rural, urban, municipal, interurban, or airport in the public sectors or commercial enterprises with major facilities and networks. The use of spatial coordinates and GPS, GIS, and intelligent vehicle highway system technologies are going to have a dominant influence on the new generation of systems and the approach to the management of infrastructure.

Future Directions and Need for Innovation in Pavement Management

W. Ronald Hudson, *University of Texas*
Ralph C. G. Haas, *University of Waterloo*

Pavement management has progressed from a concept in the 1960s, to a working process in the 1970s, to a significant degree of implementation in the 1980s. Pavement management principles have been formulated, and much has been learned from implementation experience at the federal, state/provincial, and local levels in various countries. By 2000 it is likely that most agencies will have pavement management systems (PMSs).

The improvement in pavement management application and implementation, however, have not been matched by improvements in the component technology of pavement management. Many problems that existed in the 1970s, such as the lack of good, long-term performance prediction models, still exist in the 1990s.

A substantial amount of innovation will be necessary if we are to realize a standardized pavement management process with widespread application. Such a PMS must be technically sound, with comprehensive underpinnings, yet have sufficient flexibility for tailoring to individual agency needs and resources. Required innovation and research should range from short-term problem solving to strategic efforts toward technology and application improvements.

Role of Research and Innovation

Research costs money, but innovation, when properly implemented, saves money, and good research produces innovation. We can speak of research and think of innovation, and vice versa. Once good research is formulated and carried out, the key is implementation.

Good research involves at least four levels of activity:

- Long-term research to solve problems that cannot be dealt with in any other way,
- Intermediate-term research requiring 5 or more years to solve problems of some depth,
- Short-term research to get quick answers, and
- Problem solving and development.

All these research levels have an implementation and training aspect. Any good innovation must be implemented, and such implementation involves technology transfer and training.

Emphasis of pavement management research for more than 30 years has largely been on short-term needs. The AASHO Road Test was the premier major research effort with long-term emphasis and adequate funding to actually solve the problem it undertook and to define the limitations of the results, which is critical to implementation. Lack of support for implementing innovations resulting from intermediate- and long-term research has left the industry with many of the same problems it faced in 1972.

The increased size and weight of vehicles operating on the world's highways have significantly increased pavement maintenance and rehabilitation costs. Construction practices and materials used for existing highways may not provide adequate performance in the presence of heavy loaded vehicles. This will be especially true if legal load limits are allowed to increase even further. The maintenance and rehabilitation needs of existing pavements must be reevaluated with respect to proposed loading and its economic effects.

The authors firmly believe that pavement management is the best mechanism for implementing pavement research results effectively and quickly. Managing pavements and implementing pavement research innovations have the same objective: to provide better pavements and benefits to pavement users. Furthermore, pavement management is the best possible framework for implementing pavement innovations. This is one of the basic tenets of systems engineering and efficient systems, whether they involve pavement management, space guidance, or any other field.

Implementing Pavement Management and Pavement Research Innovations

Institutional Issues

Important institutional issues must be resolved for pavement management to flourish and function more effectively. Agencies are slow to change, which is well documented in management practice (*1–3*). Only a completely integrated pavement management process will yield full consideration of total life-cycle costs in highway decisions and actions. Agencies must consider all aspects of the pavement life cycle, including user costs and benefits. Research is needed to transfer pavement management into the mainstream of highway agencies and to overcome resistance to organizational change.

Encouraging highway agencies to consider operations, including vehicle operation and maintenance and rehabilitation activities, during design will increase the benefits derived from any PMS. Maintainability is a key concept to be examined for pavement and bridge structures. By making highway structures easy to inspect and maintain, maintenance and rehabilitation costs will be reduced, as will vehicle operating costs. Designing maintenance and rehabilitation activities early can reduce the cost of protecting agency personnel, the time required to perform activities, and the need for special equipment. Well-planned maintenance and rehabilitation activities can also reduce the increase in vehicle operating costs caused by related congestion. Considering these factors during the design process will reduce the likelihood of creating a structure that is difficult to maintain.

Coordinated Research Plan

Many international agencies have prepared statements of pavement research needs, research plans, and programs of technology transfer. These statements are necessary, and a large amount of useful research has been conducted. However, an overview of what is required for a successful research program and the associated long-term benefits often is lacking.

To achieve success, the following should be incorporated into the overall approach: solutions to short-term problems and applications, intermediate-term research and development, strategic or long-term research, and implementation, including technology transfer and the development of research capabilities.

Because of the predominant short-term focus of pavement research, some problems identified in previous decades still limit the use of current research findings, including the development of new models. In addition, because there is no truly universal PMS available, much of the knowledge gained from experience is being lost. The experience gained in the 1950s, 1960s, and 1970s is rapidly disappearing from the scene with continued retirement of senior staff.

It is important to have an overall, coordinated plan to guide future funding and to address future needs. The following benefits can be provided by such an overall plan for PMS research:

- The means to seek and organize results of national and international research;
- Direction for future research funding and the ability for personnel to tailor research to future national needs;
- A coordinated avenue to implement innovation more readily;
- Rapid identification of limitations and shortcomings of existing and historical methods, which can lead to recognition of important research projects; and
- Integration of current knowledge, data, and research results into a coherent strategy that is consistent with long-term needs of a standardized PMS.

Elements of Successful Research

The elements of a successful research program include the following: an overall plan for short-, intermediate-, and long-term research; top-level commitment and support, plus sufficient funds; continuity of funding; flexibility and freedom for innovation; development of research capability (people, facilities, etc.); cooperation between practitioners and researchers; and dissemination of research results (publications, conferences, workshops, seminars, short courses, etc.).

Overall Plan

An integrated overall plan covering short-, intermediate-, and long-term research is particularly essential for state and national agencies. Issues of current concern might carry the primary focus, but a macro approach will allow better interaction between projects, better identification of priorities, preservation of the long-term integrity of research, and more efficient overall program management.

Commitment and Funding

Successful PMSs at both the state and local levels usually receive strong top-level commitment and support from their organizations. Similarly, pavement research programs must have such commitment and support, in addition to the commitment of the researchers themselves.

Sufficient and consistent funding with a reasonable degree of flexibility is also necessary. This is not to say that justification for funding and identification of expected payoffs are unnecessary. If these payoffs are to be realized and the opportunity for innovation is to exist, such funding support and flexibility are essential. Organizational support in terms of facilities, staff, opportunities to interact with practitioners and researchers within and outside the agency, and most important, encouragement, is also important to successful research.

Continuity of Funding

To be successful, research funding must have reasonable continuity. This does not mean a blank check, but rather the opportunity to accomplish real breakthroughs with the help of adequate support and funding. Innovation does not occur on a schedule; it happens in unique and unexpected ways and should not be restricted.

Flexibility and Freedom To Innovate

A common thread of successful, innovative research is the degree of flexibility and freedom provided to researchers. Innovation cannot be mandated. It comes from hard-working, innovative people who are not placed in a bureaucratic straightjacket of administrative control. Particularly constraining is a detailed procedural environment in which more time is spent in reporting progress than in actually doing research. A research management team should select researchers in whom they have confidence. A level of good administration, not control, is the key to success. The AASHO Road Test is a prototype of such effort, in which William Carey had the authority and the freedom to fulfill the project mandate (*4*).

Research may carry a considerable degree of risk, and the payoff in terms of implementation may be some time in the future. Thomas Edison tried more than 100 material combinations before he succeeded in producing the first electric light bulb. He "failed" his way to success.

Developing Research Capability

Research capability resides in many places, including universities, institutes, consulting organizations, and state and federal research groups. Although some of this capability has been acquired on the job, the basic source lies in universities. Many persons who are active in pavement research have postgraduate degrees and have learned the basic concepts of statistics, analysis, and other subjects required for research success.

Development of research capability requires dedicated, competent students; research support; course work; and direction from professors. Many highly regarded pavement researchers in the United States, Canada, and elsewhere, who work in public agencies and in the private sector, come from universities with extensive track records of educational excellence and research accomplishments.

It is essential that continued regeneration of research capability occur, with universities playing an integral part, and that there be a strong interaction among the public and private sectors and the universities.

Cooperation Between Practitioners and Researchers

Innovation can best be implemented if the sponsor or practicing engineer is involved from the beginning as a partner, not as a supervisor. A PMS makes this possible because the feedback for innovation hinges on the results of field use and upgrading. It is important for practitioners to recognize that there is such a thing as appropriate research methodology, which must be used to produce the best results.

Dissemination of Research Results

Research results must be disseminated internally within organizations and externally for peer review. Much internal success is measured in terms of implementation and improved efficiency and cost-effectiveness, but external judgments are important for follow-up work and long-term success. Newer techniques for disseminating results include videotapes, multimedia presentations, and user-friendly computer software.

Forums for disseminating research results include journals, conferences, workshops, and seminars. The latter two often are applicable to internal dissemination. Another important forum is represented by FHWA's Advanced Course in Pavement Management Systems, which was held in a number of U.S. cities in 1990 and 1991 and which incorporates up-to-date practice and recent research results (5).

Collective Opinion of Research Needs

Two recent studies of research needs as defined by practicing engineers were conducted (6,7). A synopsis of these study results is given here, but the reader is urged to review the full papers.

Hudson FHWA Study

In 1990 and 1991, 200 practicing engineers from the United States and 20 other countries were surveyed to determine priorities for research needed to better implement pavement management. The survey produced more than 400 research problem statements on short-term needs (4- to 5-year time frame) to implement better pavement management and long-term needs (15- to 20-year time frame) to develop better pavement management.

Hudson and de Solminihac (6) compiled, summarized, and evaluated these research needs statements. Their work formulates a rational research program to improve pavement management as envisioned by a large group of practicing engineers involved in all aspects of pavement management and at all levels of application. The items shown here received high-priority responses among a significant number of practicing engineers.

There were 204 responses, with 101 unique responses describing long-term opportunities for innovation and research needs within the pavement management area. The top-priority items are summarized by category in the following groups.

- PMS concepts (10 responses)
  1. Standardize PMS concepts.
  2. Establish methods for better data exchange between relational data bases to integrate design, inventory, and PMS data.
  3. Implement total quality management within PMSs.
  4. Develop a better understanding of and define pavement life cycles.
- Inputs and data collection (37 responses)
  5. Develop automated distress surveys.
  6. Develop the use of geographic information systems (GISs) to integrate vast amounts of PMS data.
  7. Develop a rapid automated system to determine pavement structural capacity.
- Output and performance models (27 responses)
  8. Develop improved performance curves.
  9. Correlate pavement performance to pavement design, construction, maintenance strategies, and other factors.
  10. Relate pavement performance to truck damage and user cost.
  11. Evaluate and improve existing pavement performance or life-cycle prediction techniques.
  12. Develop better distress prediction models.
- Materials and behavior (23 responses)
  13. Develop alternatives to asphalt derived from crude oil for use as resurfacing materials and for building pavements.
  14. Produce longer-life pavements by using better materials.

15. Quantify the effects of overloading pavements.

- Pavement design consideration (14 responses)

16. Develop an accurate, comprehensive method of pavement and rehabilitation design.

17. Develop mix design procedures that can relate laboratory properties to pavement performance.

- Maintenance and rehabilitation subsystems (15 responses)

18. Determine the performance of rehabilitation measures under varied and combined environmental conditions.

19. Evaluate the effect of maintenance strategies on pavement life and behavior of all pavement structures.

- Economic and cost analysis subsystems (24 responses)

20. Improve economic and user cost analyses and interaction of PMSs with priority construction projects.

21. Simplify, emphasize, and improve PMS budget optimization.

22. Determine the total return on investment from PMS development.

- Implementation and institutional issues (40 responses)

23. Standardize PMS use in order to group regional and national PMSs, and develop the ability to communicate between different PMSs.

24. Integrate all infrastructure management systems into a central management system, and standardize the use of data.

25. Interface PMSs and GISs with performance prediction models.

26. Incorporate highway engineers' experience into PMSs by using expert systems.

27. Market PMSs better.

28. Make more efficient use of PMSs.

29. Evaluate effectiveness of available PMSs.

- Other issues (14 responses)

30. Improve education of executives (e.g., municipal administrators and policy makers) in the purpose and benefits of PMSs.

For inputs and data collection, the main interest of survey respondents was the development of automated pavement condition data collection methods and the use of new data collection technology, such as weighing in motion and GISs. Some interest was shown in other areas of the data collection process, including traffic, deflection, and roughness data.

For the category of implementation and institutional issues, the concern changed from short-term to long-term. In the short-term, respondents identified the need to fully implement comprehensive pavement management and to establish training programs not only for technical personnel, but also for PMS decision makers. The main long-term concerns dealt with integrating all infrastructure management systems within highway agencies and standardization of PMSs and reference systems to permit better communication among systems.

In the area of economic and cost analysis subsystems, respondents expressed a concern for better understanding the full economic and life-cycle cost over the life of the pavement, particularly a better understanding and integration of user cost. Other concerns were expressed about quantifying the benefits of pavement management, particularly the benefits of developing a PMS and of improving the budget optimization subsystem of a PMS.

In the category of PMS concepts, the main concern for the short term and long term was the need to standardize PMS definitions and concepts. The need for better information exchange between various systems and agencies using PMSs was expressed, as well as the need to improve quality management in order to yield more reliable results.

International Society for Asphalt Pavement Study

The Futures Committee of the International Society for Asphalt Pavements (ISAP) was formed in 1990 to provide information to aid in the consideration of future directions for asphalt pavements. A draft report, *Focus on the World Future for Asphalt Technology*, was prepared in August 1990. It examined forces shaping our future environment; identified key political, economic, social, and technological issues; and discussed future strengths, weaknesses, opportunities, and threats. A final report was issued (7), which also contained the results of a survey of ISAP members on many of these key issues. The survey responses provide assistance in the development of research priorities.

The key issues in the questionnaire were classified into environmental, social, public policy/political, technical and economic categories. The issues posed required a yes or no response, a determination of priority (high, medium, or low), and the respondent's assessment on a scale of 1 (low) to 10 (high) of his or her degree of knowledge of the issue. The identity and address of the respondent were requested.

For each issue, the percentage of yes responses is indicated in the following list. The priorities in these categories are expressed as percentages of high priority. The top seven issues were identified by more than 90 percent of the respondents, with more than 50 percent of these respondents indicating that the issues should be considered a high priority. Three other issues were identified by 80 to 90 percent of the respondents, but still with more than 50 percent of respondents indicating that the issues should be considered a high priority.

Following are the top 10 issues identified, arranged in decreasing order of respondent support.

1. Structuring end-result specifications so that contractors can be held accountable for performance (98 percent/75 percent);
2. Determining benefits and costs of adding reclaimed materials to asphalt mixes (93 percent/91 percent);
3. Establishing conditions under which clear advantages can be gained by the use of modified, engineered, or premium asphalt cement binders (96 percent/71 percent);
4. Speeding up introduction and client acceptance of innovative materials, equipment, and procedures by the construction industry (93 percent/67 percent);
5. Communicating the economic importance of pavements to the public (98 percent/66 percent);
6. Developing specifications for long-term performance guarantees of paving work (96 percent/58 percent);
7. Determining premature asphalt paving failures in new construction or in maintenance interventions involving a lack of education or training (91 percent/54 percent);
8. Determining the availability and extent of education and training in the asphalt paving field (89 percent/61 percent);
9. Identifying fumes from asphalt plants and asphalt mixes and their possible effects on the health of the public and workers in the paving industry (85 percent/59 percent); and
10. Maintaining and/or increasing industry productivity combined with improved quality and performance of asphalt pavements (83 percent/56 percent).

Future of Pavement Management

We have learned a lot in the 25 years in which some form of PMS has been available. We have learned that a sound technological base plus good data; a staging requirement for implementation; and alternatives, deterioration models, and life-cycle economic evaluation are essential elements of a PMS. The following list provides some key things learned from 25 years of pavement management experience (*8*).

Even more interesting is a list that shows the activities and decisions within a complete pavement management structure. This generic form can be applied to other infrastructure components, such as water, sewer, bridges, and so on. The structure of this list needs to remain reasonably stable as we develop future technology. This does not hamper progress. Instead it provides a consistent philosophy for identifying technology improvement needs and realizing the benefits of such improvements.

What has been learned from the PMS process:

- The framework for and component activities of pavement management—the PMS process—can be described on a generic basis.
- Existing technology and new developments can be organized effectively within this framework.
- The PMS process allows complete flexibility for different models, methods, and procedures.
- Pavement management operates at three basis levels: network, project selection, and project.
- A sound technological base is critical to the process and its effective application.

What has been learned from using PMSs:

- Development and implementation of a PMS must be staged.
- Staging facilitates understanding and acceptance by various users.
- Options almost always exist and should be evaluated on a life-cycle basis; therefore, we need models for predicting deterioration of existing pavements and for developing maintenance and rehabilitation alternatives.
- Pavement management can make efficient use of available funds; however, this will not save a network if funding is below a particular threshold.
- Good information is essential to the effective application of a PMS.

Issues To Address

Several issues and needs must be addressed so that PMS technology continues to progress:

- Resolve the effects of different organizational structures.
- Identify the requirements and directions of local PMSs versus state and federal systems.
- Establish benefits of pavement management in quantitative terms.
- Integrate pavement management with maintenance management and other areas and levels of transport system management.

In addition, the following issues related to the pavement management process must be resolved:

- Establish relationships between pavement management and other facilities and infrastructure management systems, and methods for comparing results.
- Effectively use automation in data acquisition and processing, decision making, construction and maintenance operations, and so on.
- Develop better interfacing between network and project levels of pavement management.
- Develop better methods to estimate existing pavement deterioration and maintenance and rehabilitation treatments.
- Develop better ways to evaluate the effects of different vehicle weights, types, and dimensions.

Clearly, good PMS implementation and application must continue, but new ideas and innovation also are needed. No innovative, open-ended PMS research is currently under way anywhere in the world, and such research is critical. Following are the essential elements of renewing innovation in pavement management:

1. A source of funds in chunks of reasonable size; for example, $500,000 over 3 years;

2. Dedicated, zealous researchers and small interdisciplinary teams to handle such areas as pavements, economics, and statistics;
3. Reasonable flexibility and freedom for research teams;
4. Sponsors willing to accept failure as an outcome;
5. Open-minded, small groups of advisors to interact with and advise teams, but not to dictate or control them; and
6. Trust placed in research teams.

Future of PMS Technology

Following are expectations and needs of future PMSs:

1. Complete economic analysis, including user costs, will be used.
2. Definitions and terminology will become standard.
3. Routine use will be made of the Global Positioning System and GISs.
4. Routine use will be made of true performance specifications.
5. Warrantied pavements will be common.
6. Required courses will be taught in infrastructure management concepts: planning, design, construction, maintenance, and rehabilitation.
7. Integrated management systems will be routine.
8. Pavement assets will be valued monetarily to induce a profit motive.
9. Statistically correct network sampling data supplemented by detailed project data and very detailed research data will be needed.
10. Continuous monitoring to provide loads, pressures, and traffic volume will be necessary.

Changes To Expect

Advances in PMS technology will come from incremental improvements in current technology, changes in the PMS process, greater use of PMSs, new equipment and methods, and application of new technologies. New equipment and methods, along with their automation, offer some promising opportunities. They can improve PMS technology, particularly in pavement construction and maintenance.

Pavement evaluation, for instance, currently uses laser, optical, and acoustical methods to measure profile or roughness. Automated, image analysis–based methods to measure surface distress are coming on the market. High-speed deflection-measuring methods are somewhat further off, but should become available in the 1990s.

Promising technologies for construction and maintenance will mainly involve robotics for equipment and microelectronic-based automated control procedures. An example of promising new technology in construction is the development of a different method for accomplishing asphalt compaction.

Among the new technologies being considered, none has received more attention than the application of knowledge-based expert systems. These systems permit encoding of the accumulated experience of experts in various areas.

Summary

Unless solved, existing problems in research will limit the development and application of PMSs. The authors propose solutions to these problems, which they believe will facilitate the advancement of pavement management.

1. *Problem:* There has been no major research on the pavement management process in the past 10 to 15 years.

Proposed solution: Funding should be generated immediately for a 3-year, $1 million project by NCHRP or FHWA to fuel basic improvements in PMS concepts and processes.

2. *Problem:* The expansion of PMS technology during the past 20 years occurred without an adequate review of previous advances, which created inconsistent definitions of terms used worldwide.

Proposed solution: We must develop and adopt standard definitions of terms and use these definitions uniformly worldwide.

3. *Problem:* A return to normalcy is needed. Political forces seem to have taken control of pavement research and the application of PMSs.

Proposed solution: Leadership in research must be returned to strong technical personnel involved in pavements and PMS development.

4. *Problem:* Pavement managers often do not consider the total cost of PMSs.

Proposed solution: Research must be conducted to better determine the place of user cost in life-cycle costing and to assist in PMS implementation.

5. *Problem:* The idea that any engineer can carry out or supervise research is growing at high levels in organizations.

Proposed solution: It is necessary to restore the understanding that developing research skills requires experience, education, training, and such tools as advanced statistics, analysis, and so forth.

6. *Problem:* Some people believe that major research programs sometimes involve research contractors that are not considered trustworthy and that require extremely close supervision by nontechnical sponsor personnel.

Proposed solution: Strong efforts and cooperation are needed by research personnel and sponsors to correct this erroneous perception.

7. *Problem:* Information from advertisements in industry newsletters is being confused with valid implementation information.

Proposed solution: The industry must face reality in the success of new research and be honest about the level of implementation possible.

8. *Problem:* Six mandated systems at the national level exist in the United States, but there is no information on how the systems should be integrated.

Proposed solution: It is important to conduct major programs to define methods of integrating individual management systems into the required overall transportation management system.

References

1. Hudson, W. R., R. Haas, and R. D. Pedigo. *NCHRP Report 215: Pavement Management Systems Development.* TRB, National Research Council, Washington, D.C., Nov. 1979.
2. Hudson, W. R., and R. Haas. The Development, Issues and Process of Pavement Management. Presented at National Workshops on Pavement Management, Phoenix, Ariz., May 1980, and Charlotte, N.C., Sept. 1980.
3. Haas, R. The Role of Standards in Pavement Management. *ASTM Standardization News*, April 1987.
4. Haas, R., W. R. Hudson, and J. Zaniewski. *Modern Pavement Management.* Krieger Publishing Co., Melbourne, Fla., 1994.
5. Advanced Course in Pavement Management Systems. Course notes. FHWA, U.S. Department of Transportation, and TRB, 1991.
6. Hudson, W. R., and H. E. de Solminihac. Summary of Short-Term and Long-Term Research Needs for Pavement Management Innovation. Presented at 12th International Road Federation World Meeting, Madrid, Spain, May 1993.
7. Haas, R. (ed.). *Future Prospects for a Competitive Asphalt Paving Industry.* International Society for Asphalt Pavements, July 1993.
8. The Future of Pavement Management. *Better Roads*, July 1989, p. 44.

Institutional Challenges: An Agency Viewpoint

Wesley E. Wells, *Metropolitan Transportation Commission*

The Metropolitan Transportation Commission (MTC) is the metropolitan planning organization (MPO) for the San Francisco Bay Area in California. Its area of responsibility spans 9 counties, 98 cities, 7,000 mi^2, and 6 million people. There are 1,400 mi of state highways and 18,000 mi of local roads in the region. In addition to the cities and counties, 35 agencies have direct responsibilities in planning, programming, managing, and operating the transportation system. Unlike many MPOs, MTC has statutory powers and responsibilities directly related to the region's transportation system.

MTC, in concert with three cities and three counties, designed and implemented a pavement management system (PMS) in 1985, which was tailored to the needs and resources of local agencies. During the past 10 years MTC has supported this system through quarterly user meetings, technology transfer seminars, and a newsletter. Hotline support has been provided when users have problems operating the system. User documentation and ongoing training have been extensive. The PMS itself has been responsive to user needs and has continually been improved and upgraded to incorporate user suggestions, including network plotting capability; project-level evaluation procedures; concrete pavement analysis; summary reports, including a budget options analysis; and long-term impact assessment. The user base has grown over the years, and today 65 Bay Area cities and counties are using the system. In addition, more than 100 local jurisdictions nationwide have used the system.

An MPO's Viewpoint

MTC's perspective in supporting the Bay Area's PMS program focused on building a credible system, because reconnaissance of local pavement maintenance practices in the early 1980s indicated that many systems had been initiated but abandoned. In addition to ongoing support, at the heart of the MTC perspective was a resolve to use the outputs of the system to develop multiyear pavement maintenance and rehabilitation programs. This resolve in most cases required extensive policy support, because revenues were generally less than 50 percent of what was required.

The dual perspective focusing on local streets and roads and translating PMS outputs into policy does not appear to have received sufficient attention at conferences, in PMS training sessions, or in the literature. A survey of those attending the 1987 conference in Toronto indicated only a handful of local representatives. The registration list for the 1994 conference in San Antonio reveals the following breakdown: federal and state representatives, 50 percent; consultants, 25 percent; research and academic representatives, 15 percent; and regional and local representatives, 10 percent. Though local representation increased substantially from the previous conference, a representation of three MPOs and about 25 cities and counties is too small when comparing the 1 million mi of highways under state and federal responsibility with the 3 million mi of roads under local responsibility in the United States.

Unfortunately no data are available on a national scale that distinguish pavement conditions and needs of state and federal transportation systems from those of local systems. The Highway Performance Monitoring System gathers pavement condition data on federal-aid highways but does not separate information on federal-aid systems under local responsibility. A 1993 report to the U.S. Congress on the status of the nation's highways indicates that 40 percent of the pavements in the Interstate system are in fair to poor condition (present serviceability rating of 0 to 3.4), whereas 60 percent of the arterials and collectors are in this condition. Though arterial and collectors under state and federal jurisdiction are not separated from those under local jurisdiction, Bay Area data indicate that the gap in pavement condition is even wider.

There is little PMS literature on translating PMS output into financed maintenance and rehabilitation programs. Most of the literature focuses on pavement management as a tool and on data and analytic issues. The focus of implementation issues in the literature usually is on getting the tool implemented rather than used.

MTC has charted the progress of its 65 users for the past 10 years. Though high marks can be given to agencies that have sustained their commitment to using the PMS, a disappointingly low number have moved through the following seven steps for implementing a PMS:

1. Getting organized;
2. Gathering, editing, and entering data;
3. Analyzing data;
4. Evaluating data and developing programs;
5. Seeking program and budget approval;
6. Convincing policy board to adopt and implement a program and budget; and
7. Moving to next cycle.

Less than 20 percent of users have managed to get past the two toughest steps, 5 and 6, and move to the next annual cycle. Major reasons revolve around reluctance or inability to present effective arguments to their policy boards.

Recognizing Opportunities

Effectively translating PMS output into policy requires much more than producing good summary graphics. A key component of obtaining required policy actions is to recognize opportunities and take advantage of them. Four factors revolving around the national shift in emphasis from systems expansion to better managing existing systems must be used to make the argument that pavement conditions are deteriorating and funding must be increased.

- The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) requires states to develop, establish, and implement six management systems, including PMSs. Because more than 20 years of experience has gone into developing and implementing PMSs, these systems should serve as a model for other asset management systems. Further, states must work cooperatively with MPOs. This provides an excellent opportunity for PMSs to bridge the gap between state and local pavement management and to manage these pavements in one system.

- Flexible federal funding is available. ISTEA requires state PMSs to cover all federal-aid highways regardless of jurisdictional control. This increases coverage from 300,000 mi of highways under state control to 900,000 mi when federal-aid highways under local control are included. If PMSs are to make an impact on investment decisions, the opportunity to determine needs on the full 900,000-mi system and to allocate eligible funds across the entire system should not be missed.
- Institutional issues are tougher than technical ones. Jack Kinstlinger, in the preface to TRB's *Special Report 237: Moving Urban America,* states

> There is ample evidence to show that, given sufficient funding, we have most of the knowledge and skills to solve the technical problems . . . . The more difficult and vexing challenges have always been the institutional ones of achieving effective decision making among different advocacy groups, and power sharing among federal, state, and local elected officials, and bringing together and synthesizing vastly different sets of values and priorities.

If this view is accepted, more attention and resources will be spent on what happens after a PMS has been implemented.

Partnerships Can Help Deal with Institutional Issues

MTC has organized more than 35 transportation agencies in the San Francisco Bay Area into a partnership. This group has been meeting every other month for more than 2 years to grapple with the issues of planning, financing, programming, managing, and operating transportation as a single system. Multiagency programs and projects as well as new ways of doing business are being established. Legislative, planning and programming, and systems operation and management committees have been organized to help overcome parochialism, unimodal planning, and lack of environmental considerations. Individual federal, state, and local interests are being replaced by a broader transportation system perspective.

Building a Credible PMS Program

A danger in focusing only on what happens after a PMS has been implemented is that the tool itself or the factors to be considered in designing the tool may be underemphasized. The most important factor in successfully selling a PMS to upper management and policy makers is credibility. If a system lacks believability or the individuals responsible for explaining how results were determined do not understand how the system operates, chances of getting management and policy-level support are diminished.

In the early years of building MTC's PMS, several guiding principles helped sustain the program and increase the number of users. Keeping the concepts simple and building the system modularly allowed maximum user input so that the system could be developed to meet local needs. It was clear in the early 1980s that many systems had been developed primarily for state transportation departments with fairly rigorous levels of inputs and resources. The analytic concepts, data, and resource requirements were unsuited for city and county needs and capabilities. This was particularly true for smaller jurisdictions with less than 50 mi of streets, which represented about a third of Bay Area jurisdictions.

The guiding principle that helped MTC focus on translating pavement needs into policy was to link these needs to budget capabilities. After the 5-year projection of needs was refined with more detailed project-level analysis, MTC prepared a budget options report for local jurisdictions. The key element was to examine the historical level of pavement expenditures and to project this over 5 years to correspond to needs or costs. Three budget scenarios were estimated to measure impacts. The first was an unconstrained estimate in which all PMS-estimated pavement needs would be handled. This meant that the backlog of unrepaired roads would be eliminated and all roads would be brought up to good condition. The second was a minimum budget that would at least keep the jurisdiction from falling further behind in backlog and in total network-level conditions. The remaining budget scenario was somewhere between the first and second. Most jurisdictions were facing a budget increase just to get to the hold-your-own level.

As stated previously, the condition of Bay Area pavements was poor because of years of deferred maintenance. The level of budget shortfalls indicated a need to seek additional revenues. Probably the most important factor that characterizes successful PMS users in the Bay Area is the presence of a PMS champion: in an agency; that is, someone who not only persevered in gathering pavement condition data and in processing them through the PMS, but who also used the estimates of pavement needs to develop a 5-year recommended maintenance program. In addition, these PMS champions convinced upper management and policy makers to support revenue increases so that the program could be implemented.

Securing Funding

Once an agency secures a credible technical program and a PMS champion, the agency must sell the PMS. This is the toughest hurdle. Even though the PMS champion usually is an engineer or at least a technically oriented person who has a good grasp of PMS concepts, this is not what upper management and policy makers are interested in. Two extremely important lessons must be learned from this dilemma. First, building credibility, developing support for improving pavement conditions, and getting policy approval for revenue increases is not a one-shot deal—it usually takes years. Second, the frame of reference of upper management and policy makers must be completely understood and taken into account when developing a strategy for selling a PMS program.

Unfortunately, these lessons generally are learned through trial and error. What further complicates the effort is that situations differ from agency to agency. Efforts by state transportation departments to sell pavement maintenance and rehabilitation programs are quite different from such efforts by cities and counties. Generally, state-level allocation decisions involve carving up the transportation dollar, whereas local jurisdictions also must deal with a variety of competing claims outside transportation. In addition, at the state level the transportation system is understood in terms of the value of the investment, and there usually is a strong appreciation for the need to preserve that investment. The much tougher sell generally is to cities and counties in which 4-year office holders are besieged by demands for immediate funding increases for fire and police departments, education, and social programs. This often leads to the temptation to borrow money earmarked for long-term needs to pay for short-term ones, which has been demonstrated in the Bay Area, where a backlog in pavement repairs was documented at $300 million to $500 million in the early 1980s.

Recognizing the difficulty of selling a pavement repair program helps focus attention on which strategies and arguments should be used. Successful Bay Area programs generally used the following approaches:

- Involving public information and legislative staff.
- Gearing presentations to the audience, preferably keeping presentations brief—no more than 15 min if possible.
- Appealing to protect what is probably the local jurisdiction's largest investment—its pavements. Included here is the annual maintenance recommendation, a percent of total network replacement cost, which should be less than 2 percent.
- Summarizing the impacts of various expenditure levels, particularly what will happen to backlog and overall network pavement condition, and using the deterioration curve and emphasizing the "pay a little now or a lot more later" concept.
- Documenting the benefits to be gained from implementing the recommended repair program, particularly in terms of the types of repairs on specific streets, and holding work-

shops to explain basic concepts; providing tours of specific sites to show examples of problems and solutions; and making comparisons with neighboring jurisdictions, particularly if they are doing a better job of managing pavements.

- Providing options for the kinds of decisions being sought, both in terms of changes in annual budget levels for pavement repairs and in locating new sources of revenue.

This list should help PMS supporters organize and formulate a plan of attack. But they should not get frustrated if results are less than anticipated. Increasing taxes and pulling funds from other programs are not easy decisions. What is being sought usually requires reversing years of a different way of doing things. It probably will be necessary to take risks or to be confrontational in a polite way.

Institutional Challenges: An External Viewpoint

Kathryn A. Zimmerman, *ERES Consultants, Inc.*

Today the world is a very different place than it was only 20 years ago. If we look around us, we can see technologies that were either not available or that have changed dramatically from just a few years ago. Consider, for example, the computers we work on today. It wasn't that long ago that FORTRAN was taught in colleges and universities as the computer language for engineers. We worked on a mainframe computer and were required to keypunch each program line on an individual card, which was then fed into the computer. We sat back and waited while our stacks of cards were processed and hoped that none of them would get bent and that our stacks would run the way they were supposed to. Students aren't taught that way anymore. Today, most colleges and universities have computer rooms so that every student has access to a personal computer with capabilities we would not have dreamed of. Some colleges and universities even require incoming students to purchase a computer when they enroll. These changes are reflected in the ways we work today as practicing engineers.

Other changes have taken place over the past 20 years. Look at the way we view government today: It has changed dramatically. Some say these changes are a result of the Watergate scandal that arose during the Nixon administration. Before then, our elected officials were considered respected leaders and were almost untouchable. This is no longer the case. The public is not as trusting of elected officials and often is cynical in its view of government agencies. It's almost as if people look for something to support their theory that government agencies are wasting large sums of their tax dollars. And elected officials are having to defend their decisions.

Today, the public is asking for, and expecting to receive, accountability from its leaders and government agencies. How does this affect those of us involved in managing pavements? Elected officials are asking us to justify our pavement repair recommendations and the expenditure of dollars for those repairs and to explain the reasons for the decisions we're making. We're having to explain our engineering decisions in accounting terms.

As a result of this pressure, we've seen changes in the legislation that affects the way we operate our agencies. Recent legislative changes are intended to improve the performance of statewide and metropolitan transportation systems through preservation and operational and capacity enhancements. The legislation requires the implementation of six management systems to ensure that the performance of current and future transportation systems is optimized. This legislation, which has caught the attention of many transportation agencies, is changing how they will evaluate and select pavement rehabilitation projects, especially at the local level.

One change that began to be recognized at the last pavement management conference is the importance of these institutional issues to the success of our system implementations. We are no longer at a point at which technical issues are the driving force for implementing pavement management or for forcing operational changes within our organizations. Today nontechnical factors often have more of an impact on the success of pavement management systems within our organizations and on the acceptance of our programs by elected officials who control access to funds.

The question becomes, How do we react to these changes and what organizational and institutional challenges do we face when trying to deal with these changes? I believe the challenges we face can be categorized into five principal areas:

1. Communication,
2. Education,
3. Quality,
4. Teamwork, and
5. Innovation.

Only by looking at these areas will we be able to adjust to the changing environment in which we must operate.

The first challenge is in the area of communication. A network of communication exists that can link individuals throughout the world in seconds. This access provides an opportunity for us to learn about new procedures, activities, and ways of thinking about solutions to the problems we're facing.

Within our organizations, communication between employees is critical. The integration of management systems means that we will be communicating with individuals from different disciplines, and we must be able to work toward a common goal, a common vision. Therefore, we have to learn to communicate with different types of people and convey our technical information in ways they will be able to understand. We also must strive to improve our communications with the public, our primary customer. We must be able to address people's concerns and interests in an objective, systematic way to earn their trust. Pavement management is a tool that will help us communicate on a common basis and reach consensus with the diverse groups of people that have an interest in our decisions. One particular agency has linked its video from its condition survey to its computerized data base. This means that when a resident calls with a complaint about a road, an agency representative can view the latest video of the section while the resident is still on the phone. This has greatly increased the agency's responsiveness to the community.

The second challenge we will need to address is access to continuing training opportunities for our employees. As technology changes and we learn about new approaches to solving our problems, we have to provide our engineers with training opportunities so that they can incorporate these advances into their day-to-day situations. The Federal Highway Administration is making a strong commitment to training pavement management engineers at both the state and local levels, through conferences and new training courses. In the past few years we have seen courses for university professors, advanced PMS courses, train-the-trainer classes for local agencies, and a new textbook by Ralph Haas, Ron Hudson, and John Zaniewski. It becomes our responsibility as leaders within an organization to provide opportunities for people to participate in these technology transfer activities and to recognize this as an ongoing need because technology always changes.

The third challenge is to improve the quality of the processes we use to manage our highway networks, city streets, and airports, as well as the way we run our agencies on a day-to-day basis. We have to look at long-term strategies when we make decisions about pavement rehabilitation programs and consider the impact of intermodal opportunities. We must consider life-cycle costs, user costs, and other factors in our analytical programs and focus our attention on selecting the most cost-effective long-term strategies.

We also need to understand existing processes before we can improve them. We have to understand how decisions made in one part of an organization affect other parts of the organization and learn to identify all the customers of our pavement management systems and ensure that the systems we are implementing address as many of their needs as possible. We must understand our processes well enough to understand the difference between improving systems and reacting to changes so that we can be proactive rather than reactive. We have to recognize that pavement management is a process, not just a computer program. This means we need to define the goals and objectives of the process and use them to determine the data and methodologies required by our systems.

In addition, we must learn to work as part of a team if pavement management is going to be effective within our organizations. William Connor mentioned that the most successful implementations were developed with team input. The new legislation requires the implementation of six management systems; therefore, six areas with their own needs and priorities will be fighting for the same limited funding. We must work as teams to ensure that we do not introduce redundancy into our operations or duplicate efforts between divisions and to find creative solutions to problems. We must work together to integrate systems within our organizations. From all our experience with implementing pavement management, we have information that will benefit other groups within our organizations that are struggling to comply with the requirements of the Intermodal Surface Transportation Efficiency Act of 1991.

Finally, we must continually challenge ourselves to think creatively and to strive for innovation within our organizations. Ron Hudson mentioned the importance of research to keep innovative developments going. We must create and maintain organizations that accept reasonable amounts of risk and encourage employees to try new ideas and look for better ways to do things. For change to occur, we have to take risks, and to take risks, we have to feel safe and trusted, not defensive and protective. It is our responsibility to find ways for this to happen.

Do I believe we can meet these challenges? Yes, even though these aren't the kinds of things engineers are used to dealing with. I believe that through such opportunities as this conference, where people from around the world come together and share their experiences, knowledge, and successes, we will truly address the challenges ahead of us. In many cases, the people who have obtained pavement management acceptance in their organizations used innovative approaches. Opportunities are available today to make pavement management reach its potential, but we'll need to prepare ourselves with broader capabilities than we've had in the past. The challenges are there, but engineers are problem solvers, and I'm confident that we can overcome these challenges and continue to move pavement management forward.

Key Challenges for the Future of Pavement Management

Ralph C. G. Haas, *University of Waterloo*

We have had an excellent conference. From everything I hear, all participants have received some new information from it, and the conference has generated some ideas. But perhaps most important, everyone will take something home that will help them and their organizations.

I have the honor and pleasure of providing some closing remarks. We have heard many speakers and workshop groups either directly or indirectly address key challenges for the future of pavement management. My comments are "borrowed" from them to some degree, but they also represent my perception of these challenges.

Dean Carlson, in his opening address, said that the focus of the 1985 conference was to teach, that of the 1987 conference was to implement, and that of this conference was to use. And from what we have heard here, many federal, state/provincial, and local agencies around the world are making effective use of pavement management.

So what is the challenge for the future? I would suggest to you that the biggest challenge is to advance, and I would further suggest that this be considered the theme for the next conference.

Advance in what way? Certainly there will be incremental improvements in many technical and institutional areas, but we need quantum advances in the following areas:

- Using pavement management to prove that we are making wise investments (this conference is a start);
- Dealing with high staff turnover and educating new people, from senior administrators to entry-level people, in the process and technology of pavement management;
- Integrating the pavement management network and project levels;
- Planning, designing, and building better and longer-lasting pavements;
- Creating and implementing new technology;
- Creating a better climate for innovation, including the acceptance of risk; and
- Resolving institutional barriers.

Another key challenge is to retain pavement management as a distinct entity. We all recognize the need for integration with other infrastructure components, but there is a danger of losing sight of the importance of the technical underpinnings of pavement management. There is a further danger of pavement management being submerged in the broader spectrum of asset management, where it could be seen only in terms of information or data supply—that is, simply as part of accounting. This in no way is meant to diminish the importance of nontechnical, such as institutional, issues.

Challenges also represent opportunities. I suggest that there are tremendous opportunities for the new, younger people coming into this field. We all know the Hudsons, Finns, Monismiths, Darters, Patersons, Lyttons, Ullidtzes, Hickses, and many others, and I hope that history will see me included in that group. These people can justifiably take pride in what they have accomplished in the development of the pavement management process and technology and in its implementation. From this conference, however, we have left you with as many problems to solve and as many improvements needed as we were able to tackle.

For the new people coming into this field; for many of you who still have a lot of time, energy, interest, and enthusiasm left; and for the people I mentioned—I challenge you to seize the opportunities and advance the process, technology, and use of pavement management. Keep pavement management dynamic; innovate; resolve your institutional barriers; educate the new people, including new administrators; strive for quality; communicate; take risks; be proactive, not reactive; and make pavement management a truly effective decision support tool for all agency levels.

In closing, I believe that the key pavement management challenge not only is to continue to teach, implement, and use, but also to advance, not only incrementally but also in a substantial way. I hope that the next conference in this series, whether or not it uses advancement as a theme, will show that major and substantial advances in pavement management have indeed occurred.

Exhibitors

Aviar, Inc., P.O. Box 162184, Austin, Tex. 78716. Contact: James E. Kelly, 512/295-5285; fax 512/295-5285.

Deighton Associates Ltd., 112 King Street East, Bowmanville, Ontario, Canada L1C 1N5. Contact: Vicki Deighton, 905/697-2644; fax 905/697-2644.

Dynatest/SME, P.O. Box 71, Ojai, Calif. 73024. Contact: Dick Stubstad, 805/646-2230; fax 805/640-0345.

Eckrose/Green Associates, Inc., 6409 Odana Road, Madison, Wis 53719. Contact: Bill Green, 608/274-6409; fax 608/274-6688.

Engineering, Inc., 41 Research Drive, Hampton, Va. 23666. Contact: Henry K. Berry, 804/865-0100; fax 804/766-2437.

ERES Consultants, Inc., 505 West University, Champaign, Ill. 61820. Contact: Kathy Gantz, 217/356-4500; fax 217/356-4500.

IMS, Inc., 3350 Salt Creek Lane, Suite 117, Arlington Heights, Ill. 60005. Contact: Don Hardt, 708/506-1500; fax 708/255-2938.

INFRASENSE, Inc., 765 Concord Avenue, Cambridge, Mass. 02138. Contact: Susan Lutwak, 617/864-9736; fax 617/864-3884.

International Slurry Surfacing Association, 1101 Connecticut Avenue, N.W., Suite 700, Washington, D.C. 20336. Contact: John Fiegel, 202/857-1160.

K. J. Law Engineers, Inc., 42300 West Nine Mile Road, Novi, Mich. 48375-4103. Contact: Wade M. Jensen, 810/347-3300; fax 810/347-3345.

Krieger Publishing Company, P.O. Box 9542, Melbourne, Fla. 32902. Contact: Marie Bowles, 409/724-9542; fax 407/951-3671.

Metropolitan Transportation Commission, 101 Eighth Street, Oakland, Calif. 94607. Contact: Mark Martin, 510/464-7874; fax 510/464-7848.

MHM Associates, Inc., 1920 Ridgedale Road, South Bend, Ind. 46614. Contact: Jerry H. Mohajeri, 219/291-4793; fax 219/291-4800.

PASCO USA, Inc., 4913 Gettysburg Road, Mechanicsburg, Pa. 17055. Contact: Wade Gambling or George Miyakawa, 717/691-7625; fax 717/691-8211.

PAT Traffic Control Corporation, 1665 Orchard Drive, Chambersburg, Pa. 17201. Contact: Joe Cal, 717/263-7655; fax 717/263-7845.

Pavement Management Systems, 152 Main Street, Cambridge, Ontario, Canada N1R 6R1. Contact: F. W. Speers, 519/622-3005; fax 519/622-2580.

Pave Tech, Inc., P.O. Box 639, Norman, Okla. 73070. Contact: Rudy Blanco, 405/364-5553; fax 405/364-5796.

Penetradar Corporation, 2221 Niagara Falls Boulevard, P.O. Box 246, Niagara Falls, Tex. 14304. Contact: Anthony Alongi, 716/731-4369; fax 716/731-5040.

Pulse Radar, Inc., 10665 Richmond, Suite 170, Houston, Tex. 77042. Contact: Anita Scott, 713/977-0557; fax 713/977-2159.

Roadware Corporation, Route 1, Box 520, Paris, Ontario, Canada N3L 3T6. Contact: Diana Vander Deen, 519/442-2264; fax 519/442-3680.

Texas Research and Development Foundation, 2602 Dellana Lane, Austin, Tex. 78746. Contact: Stuart W. Hudson, 512/327-4211; fax 512/328-7246.

U.S. Army CERL, P.O. Box 9005, Champaign, Ill. 61826. Contact: Amy Jones-Kidd, 217/352-6511; fax 217/373-7222.

VEMAX Management, Inc., 209-15 Innovation Boulevard, Innovation Place, Saskatoon, Saskatchewan, Canada S7N 2XB. Contact: Gordon Sparks, 306/668-2828; fax 306/668-7603.

Participants

Richard Abell, Transport Research Laboratory, England
Ahmad A.H. Abulrahman, Kuwait Ministry of Public Works
Ali A. Achmar, U.S. Army Center for Public Works
Colin A. Ackehurst, Ackehurst Gardner Thomas, Australia
Frederick Yaw Addo-Abedi, Ghana Highway Authority
Juha S. Aijo, Kimmeltie, Finland
Ibrahim A. Al-Dubaba, Saudi Aramco
Abdullateef M. Aldakheel, Kuwait Ministry of Public Works
Douglas E. Alexander, Tracor
Raymond L. Alexander, New Mexico Highway and Transportation Department
Ahmad H. Aljassar, Kuwait University
Ibrahim Alkharashi, Riyadh Municipality, Saudi Arabia
David L. Allen, University of Kentucky
Barbara J. Allendorfer, Chec Consultants
Frederic R. Allez, TWS, France
David T. Anderson, VicRoads, Australia
Don E. Anderson, Houston Metropolitan Transit Authority
Kenneth O. Anderson, University of Alberta, Canada
Olov H. Andersson, Swedish National Road Administration
Cornelius W. Andres, Cape Cod Commission
Armando Aranda, San Antonio Public Works Department
Rodrigo S. Archondo, The World Bank
Roberto Z. Armijo, Secopt-UPV-Honduras
Charles Arnold, Michigan Department of Transportation
Madan G. Arora, University of Texas at Austin
Hector H. Arvizu, Mexicana Road Association
Gabriel J. Assaf, University of Quebec, Canada
Gylfi Astbjartsson, Iceland Public Roads Administration
Kasahara Atsushi
Busby Attoh-Okine, Florida International University
Roberto Avilez, Secopt-UPV-Honduras
Abaulhamid Awadh, Tanzania Ministry of Works

Gilbert Y. Baladi, Michigan State University
Rodrigo M. V. Barros, J. Silverio V.B.M. TH.M.V., Brazil
David J. Bates, Transit, New Zealand
Gianfranco Battiato, RO.DE.CO.SRL, Italy
Andrew B. Beamer, Wyoming Department of Transportation
Colin Keith Beatty, Texas A&M University
William Beck, South Carolina Department of Highways and Public Transportation
Roger J. Bermudez, Inter-American Development Bank
France Bernard, Ville de Verdun, Canada
Henry K. Berry, Engineering Inc.
Mohammand A. Bin Nakhi, Kuwait Ministry of Public Works
David G. Blake, Utah Department of Transportation
Byron Blaschke, Texas Transportation Institute
Jay Bledsoe, Missouri Highway and Transportation Department
Laura A. Bodley, ERES Consultants, Inc.
Doyt Bolling, Federal Highway Administration
Haim Bonjack, T&M Technology and Management, Israel
Tim Borg, Oklahoma Department of Transportation
Elizabeth S. Boswell, Texas Department of Transportation
Thomas L. Boswell, Nashville International Airport
Frank V. Botelho, Federal Highway Administration
Gary E. Bowen, Rhode Island Department of Transportation
Walter Boyd, Federal Highway Administration
Bryon Breen, Idaho Department of Transportation
Robert C. Briggs, Dynatest Consulting, Inc.
Margaret R. Broten, ERES Consultants, Inc.
Betty Brown, University of Waterloo, Canada
J. Brown, Federal Highway Administration
James L. Brown, Georgetown, Texas
Joseph Bucci, Rhode Island Department of Transportation
Neeraj Buch, Texas A&M University
Wesley M. Burford, Texas Department of Transportation
Michael W. Burke, IMS, Inc.
Bill Burnett, Texas Department of Transportation
David E. Butler, IMS, Inc.
Abbas A. Butt, Engineering and Research International
Mark A. Byra, Federal Highway Administration
James K. Cable, Iowa State University
Yinyin Cai, University of Waterloo, Canada
Joseph R. Cal, PAT Traffic Control Corporation
Kenneth L. Calhoun, North Central Texas Council of Governments
Peter P. Canisius, BASt, Germany
Joaquin Caraballo, Lavtal, Consultoria Vial Latinoamericana, Colombia
E. Dean Carlson, Federal Highway Administration
Robert F. Carmichael III, Huntingdon Engineering & Environmental, Inc.
Gerardo M. Carmona, Texas Department of Transportation/Texas Transportation Institute
Jean Carrier, CRCAC, Inc., Canada
Paulo E. R. Carvalho, Brazil
Peter D. Cenek, Works Consultancy Services Ltd., New Zealand
Doug Chalman, Texas Department of Transportation
Paul K. Chan, Texas Transportation Institute
Rudy Charlie, Bureau of Indian Affairs
Alan Cheetham, Pavement Management Systems Ltd., Canada
James G. Chehovits, CRAFCO, Inc.
J. W. Chism, Texas Engineering Extension Service
Chia-Pei J. Chou, National Taiwan University
Chi A. Chow, Oakland Metropolitan Transportation Commission
Susan I. Chu, Texas Department of Transportation
Craig Clark, Texas Department of Transportation
Norman Clark, Kansas Department of Transportation

Richard Clark, Montana Department of Transportation
Don A. Cobb, Chec Consultants
Larry Cole, American Concrete Pavement Association
Chad W. Coles, Spokane County Public Works
Paul F. Coles, Caddo Public Works
John Collura, University of Massachusetts
Billy G. Connor, Alaska Department of Transportation and Public Facilities
Ceballos R. Cordova, Caminos Y Puentes Federales, Mexico
Kenneth Corns, Ohio Department of Transportation
Tito C.F. Correia, Dner-Ministerio Dos Transporte, Brazil
Juan Pablo Covarrubias, Chile
Craig Cox, Texas Department of Transportation
David O. Cox, Federal Highway Administration
John M. Craig, Texas Department of Transportation
Toby Crow, South Dakota Department of Transportation
Steven L. Cumbaa, LTRC
Jerome F. Daleiden, Brent Rauhut Engineers
Norman H. Danylo, City of Montreal, Canada
Gordon R. Daring, Vanasse Hangen Brustlin, Inc.
Michael I. Darter, University of Illinois
Hernán E. de Solminihac, Depto Ingenier ía y Gestión de la Constr., Pontificia Universidad Católica de Chile
John D. De la Garza, Texas Department of Transportation
Daniel W. Dearasaugh, Jr., Transportation Research Board
Dale S. Decker, National Asphalt Pavement Association
Richard A. Deighton, Deighton Associates Ltd., Canada
Jim Delton, Arizona Department of Transportation
Christensen R. Derald, MRC
Mirandir D.S. Dias Da Silva Dner-Ministerio Dos Transporte, Brazil
Bruce Dietrich, Florida Department of Transportation
Tung S. Dong, International Road Federation
Paul Dorsey, Maryland Highway Administration
Dick Dorwart, Pavement Management Systems
Luiz Antonio dos Santos Aranovich, Assessoria Para Projetos Especiais Ltda., Brazil
Charles R. Dotson, Loral Defense Systems
Patrick T. Downey, Texas Department of Transportation
Gregory J. Doyle, Federal Highway Administration
Lynn C. Doyle II, Geotechnical Engineering Testing Inc.
Camilla C. Drover, Australia
Bill Duckert, Wisconsin Department of Transportation
Kurt Dunn, Federal Highway Administration
Steve Ege, Hawaii Department of Transportation
Tom Eichenbaum, City of Burlington, Canada
Elie Elhindy, Aeroports de Montreal, Canada
Phil Elliot, Virginia Department of Transportation
Jon A. Epps, University of Nevada–Reno
Juan-Carlos Espinosa, Asociacion Mexicana of Caminos
Arlie N. Evans, Texas Engineering Extension Service
Denise Evans, Ontario Ministry of Transportation, Canada
Nelson Evans, Texas Engineering Extension Service
Ronald W. Evers, Federal Highway Administration
Lynne Cowe Falls, PMS Ltd., Canada
Michael Farar, Wyoming Department of Transportation
Kieran J. Feighan, PMS Ltd., Ireland
P. Joy Ferguson, Mississippi Department of Transportation
Ronald A. Ferguson, Australia Roads and Traffic Authority
Emmanuel Fernando, Texas Transportation Institute
Luiz Carlos Ferro, Dept. de Estradas de Rodagem, Brazil
Carl H. Fielder, Vermont Agency of Transportation
David Fink, Texas Department of Transportation

Fred N. Finn, Monticello, Illinois
Itamar Flamia, Dept. de Estradas de Rodagem, Brazil
David R. Fletcher, GEO/digm, Inc.
Gerry E. Foell, Bureau of Indian Affairs, U.S. Department of the Interior
Francis B. Francois, American Association of State Highway and Transportation Officials
Salí Franzoi, Escola Politécnica da Univ. de São Paulo, Assessoria Para Projetos Especiais Ltda., Brazil
Wilfred D. Frazier, Bureau of Indian Affairs, U.S. Department of the Interior
Thomas E. Freeman, Virginia Transportation Research Council
Roberto Freitas, SET Consultoria Ltda., Brazil
Enoch French, Jr., E. J. French & Son
Malcom R. Frost, Australia Roads and Traffic Authority
Jeffrey P. Frye, Bureau of Indian Affairs, U.S. Department of the Interior
Geert H. A. M. Fuchs, DHV Environment & Infrastructure, The Netherlands
Kenneth Fults, Texas Department of Transportation
Arthur M. Furber, City of Portland, Oregon
William J. Gardner, Ackehurst Gardner Thomas, Australia
Richard Garrabrant, New York State Thruway Authority
James Garrigan, Bureau of Indian Affairs, U.S. Department of the Interior
Elena A. Garza, San Antonio Public Works Department
Laszlo Gaspar, Jr., Kozlekedestudomanyi, Hungary
Dominick J. Gatto, IMS, Inc.
Richard B. Geiger, Bureau of Indian Affairs, U.S. Department of the Interior
Chuck A. Gemayel, SME
John German, City of San Antonio
David Gershonovich, Israel Public Works Department
Darrell Giannonatti, Utah Department of Transportation
David D. Gieber, Texas Department of Transportation
Rogerio Giglio, Maia Melo Engenharia Ltda., Brazil
Mark D. Ginsberg, U.S. Army Construction
Kamal Golabi, Optima
Patricio Torres Gomez, Secretaria de Communicaciones, Mexico
John B. Goodwin, Texas Department of Transportation
Gary Graham, Texas Department of Transportation
Wade L. Gramling, PASCO USA, Inc.
Stefan F. Grater, University of Texas at Austin
Steve Gray, New Hampshire Department of Transportation
William Green, Eckrose/Green Associates, Inc.
Dimitri A. Grivas, Rensselaer
Wouter Gulden, Georgia Department of Transportation
Charles Gullicks, North Dakota Department of Transportation
Oscar Gutierrez-Bolivar, Centro De Estudios De Carreter, Aerovia, Spain
Ralph C. G. Haas, University of Waterloo, Canada
Al-Ali M. Habib, Kuwait Ministry of Public Works
Deborah Hall, Texas Department of Transportation
Kathleen T. Hall, University of Illinois
James B. Hall II, Texas Department of Transportation
James R. Hallman, Pavement Management Systems, Inc.
James W. Hanks, Jr., Texas Department of Transportation
Donald L. Hardt, IMS, Inc.
Kelly Harlan, City and County of San Francisco
Robert E. Harris, City of Indianapolis
Robert L. Harris, Texas Department of Transportation
Mark H. Hartsoe, National Park Service
Torleif Haugodegard, Norway Public Roads Administration
Zhi Wei He, University of Waterloo, Canada
Stephen P. Healow, Federal Highway Administration
William Michael Hedges, Vermont Agency of Transportation
David K. Hein, JEGEL/Dynatest/Pavmatec, Canada
Lucien J. E. Heleven, Flemish Road Administration, Belgium
Mervyn G. Henderson, South Africa

Paul J. Henderson, Bureau of Indian Affairs, U.S. Department of the Interior
Claude P. Henry, Texas Department of Transportation
John J. Henry, Pennsylvania State University
Steve Henry, Georgia Department of Transportation
Keith D. Herbold, Federal Highway Administration
Judy Hewson, Texas Department of Transportation
Argus Heyn, Parand Department of Highways, Brazil
John J. Hickey, Jr., Pennsylvania Turnpike Commission
R. G. Hicks, Oregon State University
Loren Hill, Minnesota Department of Transportation
Sonya H. Hill, Federal Highway Administration
Carl Hoffstedt, Minnesota Department of Transportation
Frank Holt, Eckrose/Green Associates, Inc.
David S. Holton, Twain Harte, California
Michael E. Hooper, E-Systems, Inc.
Razi S. Hosseni, San Antonio Public Works Department
Michel J. Hovan, FAA Technical Center
Stuart W. Hudson, Texas Research and Development Foundation
W. Ronald Hudson, University of Texas at Austin
Heinz Hueppi, Viaconsult/Hueppi AG, Switzerland
John E. Huffman, Brown & Brown, Inc.
Frederick Hugo, University of Texas
Frannie F. Humplick, The World Bank
Thomas R. Hunt, Colorado Department of Transportation
William A. Hunter, Loral Defense Systems
Michel Huot, University of Waterloo, Canada
Junius Hutabarat, Indonesia Ministry of Public Works
Yoo In-Kyoon, Korea Institute of Technology
Chung Indcoltd, ChungJo Ind. Co., Korea
Lynne H. Irwin, Cornell University Local Road Program
Newton C. Jackson, Lacey, Washington
Jan M. Jansen, Danish Road Institute
Johnny M. Johansen, ViaNova AS, Norway
Eric G. Johnson, Alaska Department of Transportation and Public Facilities
Glenn M. Johnson, Lea Asset Management Systems, Canada
Michael J. Johnson, Pavement Management Systems, Canada
John A. Johnston, City of Victoria, Tex.
Kevin B. Jones, Iowa Department of Transportation
Gerrit J. Jordan, Jordan & Joubert, Inc., South Africa
Philip B. Joubert, Stewart Scott Inc., South Africa
Pierre Joubert, SETRA, France
Douglas S. Judd, MBS, South Africa
Andris A. Jumikis, New Jersey Department of Transportation
Peter Kadar, Australia
Matt A. Karan, Pavement Management Systems, Canada
Tom Kazmierowski, Ontario Ministry of Transportation, Canada
Imre Keleti, Betonutepito RT, Hungary
Charles G. Kemper, U.S. Army Corps of Engineers
William J. Kenis, Federal Highway Administration
Gerhard Kennepohl, Ontario Ministry of Transportation, Canada
Perry M. Kent, Federal Highway Administration
David S. Keough, National Park Service
Henry R. Kerali, The University of Birmingham, United Kingdom
Sue M. Khalil, Canada
Magbool A. Khatri, Huntingdon Engineering & Environmental, Inc.
Colleen Kissane, Connecticut Department of Transportation
Abraham Kissimbo, Tanzania Ministry of Works
Bente Kloster, Danish Road Institute
Kenneth Knox, Ontario Ministry of Transportation, Canada
Freddy Knudsen, Denmark Road Directorate

Don Kobi, Roadware Corporation
Lee A. Kolesnikoff, New York State Thruway Authority
Ram B. Kulkarni, Woodward Clyde Consultants
Pat Kusick, Bureau of Indian Affairs, U.S. Department of the Interior
Jerome F. Lacher, Bureau of Indian Affairs, U.S. Department of the Interior
Scott R. Lambert, Texas Department of Transportation
Robert Lanier, City of Houston
Jo A. Lary, Pavement Consultants, Inc.
Pierre Leblond, Ministère des Transports du Québec, Canada
Shu H. Lee Departmento De Estradas, Brazil
Stephen Q. S. Lee, R.M.O.C., Canada
Joseph P. Leidy, University of Texas at Austin
Mark Leja, California Department of Transportation
Philippe Lepert, L.C.P.C., France
Michael Liggin, IMS, Inc.
Robert B. Lindsay, South Africa
Dave Lippert, Illinois Department of Transportation
Edward M. Little, Bureau of Indian Affairs, U.S. Department of the Interior
Moshe Livneh, Transportation Research Institute, Israel
Byron N. Lord, Federal Highway Administration
David S. Lowry, Cape Town City Engineers Department, South Africa
Greg Lowry, Colorado Department of Transportation
David R. Luhr, Roadware Corporation
Erland O. Lukanen, Braun Intertec
Elizabeth Lukefahr, Texas Department of Transportation
Robert L. Lytton, Texas A&M University
Donaldson R. MacLeod, D. R. MacLeod, Canada
Gunther K. Maerschalk, PM-Consult, Germany
Greg A. Malatek, Texas Department of Transportation
Vesa Mannisto, FINNRA, Finland
Mark D. Martin, Oakland Metropolitan Transportation Commission
Timothy J. Martin, Texas A&M University
David Martinez, Atser Corporation
Jacobo Martos, San Severo-18, Spain
Robert R. Mason, City and County of San Francisco
Ronnie Massey, West Virginia Department of Transportation
Jorge J. Matheu-Amaya, NHI/PIH
William H. Mathies, Michigan Department of Transportation
Welford D. Mbvundula, SATCC/TU, Mozambique
John R. Mbwana, Cornell University
Philip B. McCord, Louis Berger International
Frank R. McCullagh, Transportation Research Board
Frank McCullough, Center for Transportation Research
Mark W. McDaniel, Texas Department of Transportation
Randy McDonald, Federal Highway Administration
Ronald L. McNamara, Florida Department of Transportation
Sue McNeil, Carnegie-Mellon University
Brian McWaters, Iowa Department of Transportation
Euler Merlin, AMPLA-Engenharia de Projectos Ltda., Brazil
John R. Metcalf, Louisiana State University
Paulo R. Meurer, Departmento de Estradas, Brazil
Byron Miller, Texas Department of Transportation
Jerry C. Miller, Nebraska Department of Roads
Alaeddin Mohseni, PCS/LAW Engineering
Carl L. Monismith, University of California, Berkeley
Lucinda M. Moore, Oregon Department of Transportation
Robyn Moore, Washington State Department of Transportation
Gilbert C. Morier, TAC/PIARC 95, Canada
Abe Mouaket, Ontario Ministry of Transportation, Canada
Jackson Mrema, Tanzania Ministry of Works

Michael R. Murphy, Texas Department of Transportation
Tim Murray, Engineering Consultant, Australia
Julius Ndyamakama, Tanzania Ministry of Works
Bonnie Neglia, University of Waterloo, Canada
Parker R. Nelson, John Holland Construction & Engineering, Australia
Jose B. Neto, Dner-Ministerio Dos Transporte, Brazil
David E. Newcomb, University of Minnesota
Marceline J. Newman, Texas Department of Transportation
Lee Chian Ng, Singapore
James Ngarkok, University of Texas at Austin
Toan Nguyen, City of Austin Public Works
James E. Nichols, Nichols Consulting Engineers
John E. Nichols, Federal Highway Administration
Daryl Nixon, Saskatchewan Department of Highways and Transportation, Canada
Robert L. Novak, IMS, Inc.
Frank Nyangaga, Texas A&M University
Bob Oddson, Ontario Ministry of Transportation, Canada
Eric Oduro-Konadu, Ghana
Tulay Ogras, Turkish Highway Department
Arnold Oliver, Texas Department of Transportation
Paul A. Olivier, Dynatest Africa, South Africa
Ingmar Olofsson, RST Sweden AB, Sweden
Mohamed I. Omran, Saudi Arabia
Mary C. Oppermann, North Carolina Department of Transportation
Fredrick Orloski, Federal Highway Administration
Deborah P. Ortiz, I.T.R.E.
Gerard Paget, The World Bank
David Paine, Pavement Management Services, Australia
Masoud Pajoh, Oklahoma Department of Transportation
Richard C. Panuska, Engineering Incorporated
Abraham J. Papenfus, TDA Roads Branch, South Africa
Gina Pastrano, Texas Department of Transportation
Harilal I. Patel, Bureau of Indian Affairs, U.S. Department of the Interior
Kanu U. Patel, Bureau of Indian Affairs, U.S. Department of the Interior
William D. Paterson, The World Bank
Donald F. Patrick, Federal Highway Administration
Steve A. Pax, ERES Consultants, Inc.
Edmond G. Payne, Bureau of Indian Affairs, U.S. Department of the Interior
Derek I. Pearson, England
Olga J. Pendleton, Texas Transportation Institute
Djalma Rocha Martins Pereira, ENGEFOTO, Engenharia e Aerolevantamentos S/A, Brazil
Eric J. Perrone, Texas Research and Development
David G. Peshkin, ERES Consultants, Inc.
Katherine Petros, Federal Highway Administration
Stephen J. Phillips, Department of Transport, England
Michael C. Pietrzyk, Center for Urban Transportation Research, University of South Florida
Charles C. Pilson, University of Texas at Austin
L. Enrique Pinalla, The World Bank
Michael I. Pinard, Botswana Roads Department
Wei-Chou V. Ping, FAMA/FSU College of Engineering
Stephen W. Pope, City of Tacoma Public Works
Repinalds Porath, Der-SC Highway Department Santa Catanina, Brazil
Ken F. Porter, SWR—TM, Australia
Tony M. Porter, Works Consultancy Services, New Zealand
Anand Prakash, Pavement Systems Technologies, Canada
Robert M. Prescott, N.D. Lea Consultants, Canada
A. Robert Raab, Transportation Research Board
Thomas H. Rains, Federal Highway Administration
Dante G. Ramirez, Secopt-DGCCA-Honduras
Ramesh C. Rangaswamy, Government of Karnataka Public Works Department, India

Brent Rauhut, Brent Rauhut Engineering, Inc.
Paul Redd, Loral Defense Systems
Jewelene Richardson, Transportation Research Board
Cheryl Allen Richter, Federal Highway Administration
Ian J. Rickards, Pioneer Road Services, Australia
Richard L. Ridings, HNTB Corporation
Cordell Ringel, Bureau of Indian Affairs, U.S. Department of the Interior
Michael C. Riojas, SABC, MPO
Rolands Rizenbergs, Kentucky Transportation Cabinet
Elias Rmeili, Texas Department of Transportation
Freddy L. Roberts, Louisiana Tech University
Neil F. Robertson, Queensland Department of Transport, Australia
Christopher Robinson, University of Texas at Austin
Shirley Rodenborn, Oakland Metropolitan Transportation Commission
Vance I. Rodgers, City of Austin Public Works Department
Luis M. Rodriguez, Federal Highway Administration
Gerald J. Rohrbach, Minnesota Department of Transportation
David A. Rose, Ninham Shand, Inc., South Africa
Giora Rozmarin, Israel
Brian Ruck, Ontario Ministry of Transportation, Canada
Weldon E. Rudd, Texas Department of Transportation
Timo P. Saarenketo, Texas Transportation Institute
Jani P. Saarinen, FINNRA, Finland
Paul E. Sachs, Tacoma, Washington
Enrico Salvatori, SI PRO MA SRL, Italy
Naveed Sami, IMS, Inc.,
Nascimento Saulo, Department de Estradas de Rodagem, Brazil
Ivan F. Scazziga, Viaconsult Ltd., Switzerland
J. David Scherling, Florida Department of Transportation
Jimmie Schindewolf, City of Houston
Edwin R. Schmeckpeper, University of Idaho
Randy L. Schnicker, City and County of Denver
Cameron Schultz, Rensselaer
Harris Scott III, Tennessee Department of Transportation
Tom Scullion, Texas Transportation Institute
Ali A. Selim, South Dakota State University
Lee Seong, Government Office, Korea
James H. Shackelford, City of Indianapolis
Micheal C. Shackleton, Transporter, CSIR, South Africa
Douglas L. Shaffer, Transportation Research Board
Mohamed Y. Shahin, U.S. Army Corps of Engineers
Brij Sharma, Ontario Ministry of Transportation, Canada
Subramanan N. Sharma, New Hampshire Department of Transportation
Gary W. Sharpe, Kentucky Department of Highways
Grant Sheldon, Australia
Li Shifeng, University of Texas at Austin
Robert E. Shonkwiler, Fresno County Public Works
Sam Sidawi, City of Burlington, Canada
Rick Sims, Roadware, Canada
Omar G. Smadi, Iowa Transportation Center
Paul Smith, Delaware Department of Transportation
Robert B. Smith, CMPS & F Pty Ltd., Australia
Robert W. Smith, Poe & Associates, Inc.
Roger E. Smith, Texas Transportation Institute
Martin S. Snaith, University of Birmingham, United Kingdom
Jim I. Snell, M.A.C.C.
Jeanne S. Soegeng, Indonesia Ministry of Public Works
Rodney C. Soule, Harding Lawson Associates
Maria L. Souza, Dner-Ministerio Dos Transporte, Brazil
Gordon A. Sparks, VEMAX Management, Inc., Canada

Jack H. Springer, Federal Highway Administration
Mate Srsen, Civil Engineering Institute of Croatia
Gary R. St. Michel, Lea Asset Management, Canada
Bill Staggs, Arkansas State Highway and Transportation Department
Bryan E. Stampley, Texas Department of Transportation
John E. Statton, Australia Department of Transport
Richard K. Steger, Texas Department of Transportation
Shelley M. Stoffels, Pennsylvania State University
George Strout, Federal Highway Administration
Angelia A. Summons, Transportation Research Board
Even K. Sund, University of Trondheim, Norway
Daniel L. Sunde, Washington State Department of Transportation
Paul L. Sunwoo, Bureau of Indian Affairs, U.S. Department of the Interior
George Suzuki, PASCO USA, Inc.
Mark Swanlund, Federal Highway Administration
Govert T. H. Sweere, SHRP, The Netherlands
Bill S. Swindall, Roadware Corporation
Raimo Tapio, Finnish National Road Administration
Arthur Taute, Van Niekerk, Kleyn & Edwards, South Africa
Bobbie F. Templeton, Texas Department of Transportation
Joe B. Thompson, Texas Department of Transportation
Paul D. Thompson, Cambridge Systematics, Inc.
Tuomas Toivonen, FINNRA, Finland
Jacques M. Tollie, The World Bank
Simon Tran-M-Trung, National Park Service, U.S. Department of the Interior
Alton Treadway, Alabama Department of Transportation
George Trnka, The World Bank
David C. Turner, Pulse Radar, Inc.
Matthew Turo, Massachusetts Highway Department
Waheed Uddin, University of Mississippi
Per Ullidtz, Technical University of Denmark
Ray A. Van Cauwenberghe, Manitoba Highways and Transportation, Canada
Randall Van Gorder, Bureau of Indian Affairs, U.S. Department of the Interior
Marthinus J. Van Heerden, MSAICE, South Africa
Gert C. Van Niekerk, Van Niekert & Associates, South Africa
Gerhardt D. Van Zyl, Transporter, CSIR, South Africa
Izak C. Van der Vyver, MSAICE, V+V, Inc., South Africa
Karen VanHooser, Texas Department of Transportation
Andre Vandergryp, South Africa
Hillar Varik, Estonian Road Administration
A. Veeraragavan, Bangalore University, India
Johan Viktor, Van Wyk & Louw Consulting Engineers, South Africa
Stephen P. R. Vincent, Scott Wilson Kirkpatrick, United Kingdom
Pertti K. Virtala, Ithaca, New York
Alex T. Visser, University of Pretoria, South Africa
Vinko Vodopivec, Pot, Slovenia
Peter von Feilitzen, IMS, Inc.
Jian-Neng Wang, University of Texas
Kelvin C.P. Wang, University of Arkansas
Li Wang, University of Illinois at Urbana-Champaign
James Waugh, Sinclair Knight Merz, Australia
John Weaver, Indiana Department of Transportation
Richard Weeks, Maine Department of Transportation
Pieter A. C. Weidemann, TPA Roads Branch, South Africa
Robert Weinstein, Florida Department of Transportation
William R. Weiss, ERES Consultants, Inc.
Charles T. Wells, Pulse Radar, Inc.
Wesley E. Wells, Oakland Metropolitan Transportation Commission
Donald R. West, Tarrant County, Texas
David R. Whitcher, Olympia County Road Administration Board

William G. Whitcomb, City of Vancouver
Ronald P. White, ECM, Inc.
Thomas D. White, Center for Transportation Research
Sumaryanto Widayatin, Indonesia Ministry of Public Works
Paul W. Wilke, C&S Engineers, Inc.
Dawson M. Wilkie, Townsville City Council, Australia
Steve J. Wilkie, Bureau of Indian Affairs, U.S. Department of the Interior
Andrew Wimsatt, Texas Department of Transportation
Larry J. Wiser, Federal Highway Administration
Evan J. Wisniewski, Federal Highway Administration
J. B. Wlaschin, Federal Highway Administration
Robert F. Wolf, National Park Service, U.S. Department of the Interior
Ronota A. Woodbridge, Federal Highway Administration
Robert E. Woods, Indiana Department of Transportation
Shie S. Wu, North Carolina Department of Transportation
Angeles Yanez, Ministerio De Obras Publicas, Spain
Dingyl Yang, University of Texas at Austin
John A. Yant, Texas Department of Transportation
Margot T. Yapp, Monterrey County, California
Tom M. Yarbrough, Texas Department of Transportation
Reuven Yom-Tov, Israel Public Works Department
John P. Zaniewski, Arizona State University
Jeff Zavitski, Deighton Associates Ltd., Canada
James H. Zeigler, Tennessee Department of Transportation
Zhenming Zhang, University of Texas at Austin
Kathryn A. Zimmerman, ERES Consultants, Inc.
Gabryel Zoltan, Israel

Steering Committee and Liaison Representative Biographical Information

Steering Committee

Ralph C. G. Haas, *Chairman,* is an educator and highway researcher. He obtained his bachelor and master's degrees from the University of Alberta and his Ph.D., from the University of Waterloo. He is Norman W. McLeod Engineering Professor, Department of Civil Engineering, University of Waterloo, where he has been since 1968. He was chairman of the Department of Civil Engineering at the University of Waterloo from 1983 to 1989 and was Visiting Professor at the University of Texas at Austin in 1978, 1973, and 1970. He has conducted research in economics, management, and technology of highway pavements and has published extensively. He is a member of the American Society for Testing and Materials (ASTM), the Association of Asphalt Pavement Technologists, and the Canadian Technical Asphalt Association. He is a Fellow of the Canadian Academy of Engineering and a Fellow of the Canadian Society of Civil Engineering. He is a member and past chairman of the TRB Pavement Management Committee and a past member of the NCHRP Panel on Maintenance Levels-of-Service.

Billy G. Connor, *Vice Chairman,* is a Resident Engineer with the Alaska Department of Transportation and Public Facilities. He has worked for the department for 23 years in design, construction, and research. In his present position he manages a number of construction projects, including airport and highway construction, throughout Alaska. During his career he managed the development of Alaska's pavement management system. He is a former chairman of the TRB Committee on Pavement Management. He holds a bachelor's degree in civil engineering and a master's degree in engineering management from the University of Alaska. He received the K. B. Woods Award from TRB in 1982.

William D. O. Paterson, *Vice Chairman,* is a Senior Highway Engineer for the East Asia and Pacific region with the World Bank. He has an honors degree in Civil Engineering and a doctorate from the University of Canterbury in New Zealand. He worked in pavement engineering research, road construction, and pavement management for 15 years in South

Africa, New Zealand, and Southeast Asia before joining the World Bank in 1981. He was one of the developers of the World Bank's HDM-III model for economic evaluation of highway expenditures, which is used widely for economics-based pavement management. He advises on highway expenditures, policies, and programs in developing countries and is aware of a broad range of highway management technology and practice in developed and developing countries. He has authored two books and numerous technical papers. He is a member of ASTM's Committee on Pavement Management Technologies and the TRB Committees on Pavement Management and on Surface Properties–Vehicle Interaction. He is a past member of the Axle Loading Task Group of the Trucking Research Institute, technical committees of the Permanent International Association of Road Congresses and the Organization for Economic Cooperation and Development, and of the NCHRP Panel on Measurements, Specifications, and Achievement of Smoothness for Pavement Condition.

David T. Anderson is a Senior Transportation Executive in the state of Victoria, Australia. He holds a master of business administration from the International Management Center, United Kingdom; a master of science in transportation from the University of California, Berkeley; a bachelor of engineering from the University of Melbourne; and a diploma of civil engineering from the Gordon Institute of Technology in Victoria. He has held many positions with the Victorian State Road Authority, currently known as the Roads Corporation (trading as VicRoads). During the past 26 years he has been responsible for road design and construction, bridge design and construction, and corporate planning. He was Regional Manager for Western Victoria from 1987 to 1989. From the late 1970s to the mid-1980s he was manager of the VicRoads pavements group, at a time when new pavement design technology was introduced to Victoria. He convened a national working group charged with introducing uniform pavement management practices to Australia. Since then, as a member of the corporate management group of VicRoads, he has retained an interest in the development of maintenance management and pavement management within Victoria. He is a member of the Australian Institute of Engineers and is responsible for coordination of road safety management on behalf of VicRoads.

Albert J. Bush III received his bachelor's and master's degrees from Mississippi State University and his Ph.D. From the University of Illinois. He is currently Chief, Technology Applications Branch, Airfields and Pavements Division, U.S. Army Engineer Waterways Experiment Station. He has been with the Waterways Experiment Station since 1968. He holds a professional engineering license in the state of Mississippi. He is chairman of the TRB Pavement Management Section, a member of ASTM, and a member and past chairman of the TRB Committee on Strength and Deformation Characteristics of Pavement Sections.

László Gáspár, Jr., is a transportation engineer and researcher. He received master's degrees in highway engineering and economic engineering from the Technical University of Budapest and his Ph.D. from the Hungarian Academy of Sciences. He was Construction Engineer, Asphalt Pavement Construction Firm, Budapest, Hungary, from 1966 to 1968; Head, Construction Laboratory, Highway Construction Firm of Pest County, Budapest, Hungary, from 1968 to 1970; and Researcher and Manager, Institute of Transport Science Ltd., Budapest, Hungary, from 1971 to the present. He has been a consultant to the World Bank since 1986.

John J. Henry is an educator and a mechanical engineer. He received his bachelor's, master's and Ph.D degrees from Massachusetts Institute of Technology. He is Director of the Pennsylvania Transportation Institute and Professor of Mechanical Engineering at Pennsylvania State University. For the past 15 years he has been engaged in research on pavement skid resistance and surface characteristics. He is vice chairman of ASTM's Committee on Traveled Surface Characteristics and is ASTM representative to the Permanent International Association of Road Congresses. He is a past chairman of the TRB Committee on Surface Properties–Vehicle Interaction and Chairman of the ASTM Committee on Pavement Management.

R. Gary Hicks is Professor of Civil Engineering at Oregon State University. He has more than 30 years of experience in research and practical training in the areas of pavement materials, pavement design and evaluation, and maintenance and rehabilitation of highway and airfield pavements. After completing B.S. and M.S. degrees at the University of California at Berkeley, he worked for Woodward-Clyde Consultants from 1965 to 1970. After completing his Ph.D., he joined the faculty of civil engineering at Georgia Tech in 1971 and that of Oregon State University in 1975. He has participated in a number of projects related to asphalt-aggregate mixes (conventional and modified), pavement evaluation and design, and pavement management. In particular, he worked on significant projects such as the 1986 AASHTO Guide for Design of Pavement Structures, SHRP Project A-003A (Performance Related Testing and Measuring of Asphalt-Aggregate Interactions), and numerous pavement design and rehabilitation projects. He has authored numerous publications in these areas and has lectured throughout the world on these topics. He is coauthor with Clarkson Oglesby of the textbook *Highway Engineering*. He is a registered civil engineer and is active in professional organizations such as TRB, ASTM, and the Association of Asphalt Paving Technologists (AAPT).

Jo Lary is a transportation administrator. She received her B.A. from the University of Minnesota and her B.S.C.E. and M.S.C.E. from the University of Washington. She is president of Pavement Consultants, Inc., which she cofounded, and has 10 years of experience in the pavements area. She was a research engineer at the University of Washington from 1982 to 1984 and Assistant Soils Engineer at Dames and Moore from 1984 to 1985. She is a member of the TRB Committee on Rigid Pavement Design, ASCE, NSPE, Chi Epsilon, Tau Beta Pi, and Phi Kappa Phi. She received the K. B. Woods Award from TRB in 1985.

Joe P. Mahoney is an educator and highway researcher. He received B.S.C.E., M.S.C.E., and Ph.D. degrees from Texas A&M University. He has been Professor of Civil Engineering at the University of Washington since 1979 and holds the Inger and Allen Osberg Professorship. He has been involved in pavement-related activities since 1969. He is a past chairman of the TRB Section on Pavement Management and of the Committee on Flexible Pavement Design. He is a member of the TRB Committee on Pavement Rehabilitation. He received the K. B. Woods Award from TRB in 1985 and 1987.

Brian R. McWaters received a B.S.C.E. from the University of Minnesota in 1973. He is Pavement Engineer, Office of Road Design, Iowa Department of Transportation. He has been with the Iowa Department of Transportation since 1973 in both design and construction capacities. He is Chairman of the AASHTO Joint Task Force on Pavements and a member of the TRB Committees on Rigid Pavement Design and on Flexible Pavement Design, the AASHTO Task Force on Pavement Design Systems, and NCHRP Project Panels 1-30 (Support Under Portland Cement Concrete Pavements) and 1-32 (Systems for Design of Highway Pavements). He is a registered professional engineer in the state of Iowa.

Carl L. Monismith received his bachelor's and master's degrees from the University of California, Berkeley. He is Robert Horonjeff Professor of Civil Engineering at the University of California, Berkeley, where he has been since 1951. He is a Fellow of the American Society of Civil Engineers, a member of the National Academy of Engineering, and an Honorary Member of the Association of Asphalt Paving Technologists, the American Society for Engineering Education, Chi Epsilon, Tau Beta Pi, and Sigma Xi. He is a Fellow of the AAAS and a member of ASTM's Committee on Road and Paving Materials. He has served as Chairman of the Pavement Design Section and as a member and chairman of a number of committees of TRB. He received the Association of Asphalt Paving Technologists' W. J. Emmons Award in 1961, 1965, and 1985; the TRB K. B. Woods Award in 1971; the University of New South Wales' Rupert Meyer Award in 1976; the James Lurie Prize from ASCE in 1988; and the TRB Distinguished Lecturer Award in 1992. He was placed on the Asphalt Institute Roll of Honor in 1990. He is a licensed civil engineer in California. His research areas include asphalt pavement design and rehabilitation.

David E. Newcomb received bachelor's and master's degrees from Texas A&M University and a Ph.D. from the University of Washington. He is Miles Kenter Land Grant Professor at the University of Minnesota, where he has been since 1989. From 1980 to 1983 he was a Research Engineer with the New Mexico Engineering Research Institute, University of New Mexico; from 1983 to 1986 he was Research Assistant, University of Washington; and from 1986 to 1988 he was Assistant Professor, University of Nevada, Reno. He was awarded TRB's Fred Burggraf Award in 1989. He is a member of ASCE, ASTM, and the Association of Asphalt Paving Technologists. He is Chairman of the TRB Committee on Pavement Rehabilitation.

Freddy L. Roberts is an educator and engineer. He received B.S.C.E. and M.S.C.E. degrees from the University of Arkansas and a Ph.D. degree from the University of Texas. He is T. L. James Professor at Louisiana Tech University, where he has been since 1990. He was Director, National Center for Asphalt Technology, Auburn University, from 1986 to 1990; Associate Professor, Texas A&M University, from 1983 to 1986; Research Associate, University of Texas, from 1981 to 1983; Chief Engineer, Austin Research Engineers, from 1978 to 1981; Visiting Professor, University of Texas, from 1975 to 1977; and Associate and Assistant Professor, Clemson University, from 1969 to 1975. He is a member of AAPT and ASCE and serves on the TRB Committee on Flexible Pavement Construction and Rehabilitation and on the NCHRP Project Panel on Calibrated Mechanistic Structural Analysis Procedure for Pavements and Laboratory Determination of Resilient Modules for Flexible Pavement Design. He is a past chairman of the TRB Committee on Pavement Monitoring, Evaluation, and Data Storage.

Gary Wayne Sharpe received B.S.C.E. and M.S.C.E. degrees from the University of Kentucky. He is an Assistant Director for the Division of Highway Design, Kentucky Transportation Cabinet, where he has been since 1989. He was with the Transportation Center of the University of Kentucky from 1981 to 1989 and with the Kentucky Transportation Cabinet, Division of Research from 1975 to 1981. He holds both Professional Engineer (civil) and Land Surveyor's registrations in the state of Kentucky. He serves on the following TRB Committees: Rigid Pavement Design, Flexible Pavement Design, and Pavement Rehabilitation. He is a past member of the Committee on Strength and Deformation Characteristics of Pavement Sections. He is a member of the AASHTO Joint Task Force on Pavements.

Roger E. Smith is an educator and highway researcher. He received a B.A. from Wabash College and B.S.C.E., M.S.C.E., and doctoral degrees from the University of Illinois. He is Associate Professor and Associate Research Engineer, Texas A&M University, Texas Transportation Institute where he has been since 1986. He was an officer in the U.S. Army Corps of Engineers from 1968 to 1975, Research Assistant at the University of Illinois from 1976 to 1979, Soils and Materials Engineer with Hurst-Rosche Engineers from 1979 to 1980, and Technical Director, ERES Inc., from 1980 to 1986. He is a member of the Society of American Military Engineers, the American Public Works Association, Chi Epsilon, and Tau Beta Pi. He is Chairman of the TRB Committee on Pavement Maintenance and a member of the TRB Committee on Pavement Monitoring, Evaluation, and Data Storage.

Per Ullidtz is an educator and transportation researcher. He received master's and doctoral degrees from the Technical University of Denmark. He has been an Associate Professor at the Technical University of Denmark since 1976. From 1966 to 1968, he was in the Danish Air Force and worked on the design of military installations. He was executive engineer, Central Materials Laboratory, Ministry of Works, Uganda, from 1968 to 1969; teacher, Kenya Polytechnic Building Department, Nairobi, Kenya, from 1969 to 1970; geometric design and construction engineer for Kampsax A/S, Denmark, from 1973 to 1975; consultant to the Danish Roads Directorate, Technical University of Denmark, from 1975 to 1976; Visiting Professor, Ecole Polytechnique Federale de Lausanne, Switzerland, from 1987 to 1988; Managing Director, GeRoute Dynatest France, from 1989 to 1991; and Professor, Technical University of Lund, Sweden, from 1989 to 1991. He is a member of the Danish Society of Civil Engineers, La Societe des Ingenieurs et Scientifiques de France, the Danish Society of Highway Engineers and Town Planners, the Scandinavian Road League, the European Flexible Pavement Study Group, the Association of Asphalt Paving Technologists, the International Society for Asphalt Pavements, and the Transportation Research Board. He is a member of the TRB Committees on Pavement Management Systems and on Strength and Deformation Characteristics of Pavement Sections.

Wesley E. Wells is senior transportation analyst for the Metropolitan Transportation Commission (MTC) in the San Francisco Bay Area. He holds a bachelor's degree from the University of Hawaii and a master's degree from the University of Arizona. In his 25 years with MTC he has managed a program for a motorist aid system of roadside call boxes and roving tow trucks; supervised the development of management and operations strategies to integrate regional freeway, arterial, and transit services; and built a pavement management system currently used by 68 Bay Area cities and counties and more than 100 other agencies nationwide. He was employed by the Bay Area Transportation Study from 1965 to 1971, where his responsibilities included the management of the information and analytic section, and later the planning section. He is the author of numerous papers on the development of the MTC pavement management system for both the Transportation Research Board and the North American Conferences on Managing Pavements.

Kathryn (Cation) Zimmerman received B.S.C.E. and M.S.C.E. degrees from the University of Illinois. She is a transportation consultant. Her previous position was President and Chief Executive Officer of ERES Consultants; prior to working for ERES she was with the U.S. Army Corps of Engineers Construction Engineering Research Laboratory. She holds professional engineering licenses in Illinois, New Jersey, Florida, and Louisiana. She chairs the TRB Committee on Pavement Management Systems and is a member of the ASCE Airfield Pavement Committee, the National Society of Civil Engineers, and ASTM.

Liaison Representatives

Lawrence W. Cole is Vice President—Engineering and Research for the American Concrete Pavement Association (ACPA). He received a bachelor's degree in civil engineering from Utah State University. His professional background includes experience as Director of the Portland Cement Association's Paving and Public Works Department, design engineer with the Wyoming Highway Department, and pavement construction contracting with the Southern Concrete Paving Company. He is a member of the TRB Committees on Rigid Pavement Design and on Portland Cement Concrete Pavement Construction. He is active in American Concrete Institute (ACI) Committee 325 on Concrete Pavements and ACI Committee 330 on Concrete Parking Lots. He is responsible for ACPA's technical and research department, which produces ACPA's technical publications and educational products and directs ACPA's technical services for members, library information, and research efforts.

Tung S. Dong has been with the International Road Federation (IRF), Washington, D.C., since 1983, where he serves as Director of Programs. He holds a bachelor's degree in civil engineering from Saigon University in Vietnam and undertook postgraduate studies in highway engineering at the Ohio State University. Mr. Dong has 40 years of highway engineering and management experience. Before joining IRF, he was Chief Engineer of the Vietnam Highway Administration, then Senior Highway Project Manager with TAMS Consultants, Inc. At IRF he directs the development and implementation of the Videotape Training and Workshop Programs on highway management, construction, operations, and maintenance. He also provides technical highway advice in connection with other IRF programs. He represented IRF on steering committees for the Second North American Conference on Managing

Pavements and the Fifth and Sixth International Conferences on Low-Volume Roads. He was a member of the Executive Committee for the Sixth International Conference on Structural Design of Asphalt Pavements.

Kenneth W. Fults, a civil engineer, is currently Director of the Pavements Section of the Design Division of the Texas Department of Transportation, where he has more than 20 years' experience in a variety of civil engineering settings and extensive management experience in materials, planning, design, and special projects areas. He received his bachelor of science degree from Texas A&M University in 1971. He has authored and coauthored many publications. He has accomplished research in the following areas: sprinkle treatment, stress-relieving innerlayers, fiber-impregnated hot mix, carbon black, fiber-impregnated soil cement, and condor soil stabilization.

Sonya H. Hill is a Highway Engineer with the Office of Engineering, Pavement Division, Pavement Management Branch of the Federal Highway Administration (FHWA). She received a bachelor's degree in architectural engineering from Prairie View A&M University. She began working for FHWA in 1970 and was the second woman to complete the FHWA Highway Engineer Training program in 1972. She has worked at all levels of FHWA and the U.S. Department of Transportation (Division, Region, Office of the Secretary of Transportation, and headquarters FHWA). She has been in the Pavement Management Branch since June 1991.

W. Ronald Hudson, a registered Professional Engineer and the Dewitt C. Greer Centennial Professor at The University of Texas, is active in bridge, pavement, and building management; teaching; and research. He has served as International Director of a $15 million UNDP research program, as Program Manager for the SHRP–LTPP Study, and as a pavement research engineer at the AASHO Road Test. He has 25 years of research and teaching experience and 11 years of practical design and field experience. He is a registered Professional Engineer in Illinois, Arizona, Kansas, Indiana, and Texas. He has served as Chairman of TRB's Pavement Section and as Chairman of the Executive Committee of the Highway Division of ASCE. He has written more than 300 technical papers and two books: *Pavement Management Systems* and *Modern Pavement Management.* He lectures and works worldwide in 17 countries. He is a past chairman of TRB's Section on Pavement Management and is a member of the TRB Committee on Pavement Management Systems. He is a member of ASCE and ASTM. He received the HRB Outstanding Paper Award in 1963, the ASCE Texas Section Outstanding Paper Award in 1965, and the James R. Cross Medal from ASCE in 1968.

Tom J. Kazmierowski, a professional Engineer, is manager of the section responsible for pavement design, evaluation, and management in the Ministry of Transportation of Ontario. He received a degree in civil/geotechnical engineering from the University of Toronto. He is a nationally recognized contributor in the field of both rigid and flexible pavement design, rehabilitation, and management. He has more than 18 years of experience in pavement investigation, evaluation, design, and rehabilitation. He has guest lectured at various universities and has authored numerous technical papers for national and international forums. He is past chairman of the Pavements Standing Committee for the Transportation Association of Canada (TAC) and Chairman of the Ontario Provincial Standards Specialty Committee on Pavements. In addition, he is Chairman of the Pavement Management Guide Subcommittee of TAC and is a member of the TAC Soils and Materials Standing Committee and the TRB Committees on Flexible Pavement Construction and Rehabilitation and on Pavement Management. In 1990 he received TAC's Gilchrist Medal for best technical paper at the annual conference.

Richard W. May is Senior Engineer of the Asphalt Institute in Lexington, Kentucky. He received a bachelor's degree in civil engineering from Drexel University and a master's degree in geotechnical engineering from the University of Maryland. He is a licensed civil engineer in Maryland. From 1975 to 1985 he developed and managed pavement research contracts at FHWA. At the Asphalt Institute, where he has been since 1985, he has developed and revised structural design charts and collected information for various design manuals and technical publications. He provides technical support, computer assistance, and structural and mix design assistance to 18 field engineers. In 1992 he finished the requirements for his Ph.D. degree while working at the Asphalt Institute. His dissertation was titled *An Analysis System for Evaluating the Structural Performance of Asphalt Concrete Mixtures.* This research led to the development of the Computer-Assisted Asphalt Mix Analysis (CAMA) computer program package currently being marketed by the Asphalt Institute. In mid-1993 he became part of the new Asphalt Institute Research and Engineering Services Division. Since 1991 he has served as Secretary of ASTM Committee D04 on Road and Paving Materials.

Richard D. Morgan is the Vice President of the National Asphalt Pavement Association responsible for working with government agencies and other trade and highway user groups on policy, regulatory, and legislative issues affecting the hot-mix asphalt industry. He began his career with the Federal Highway Administration, served in a number of progressively responsible assignments, and in 1982 was appointed Executive Director, responsible for operation of the agency in cooperation with the Federal Highway Administrator. He holds a bachelor's degree in civil engineering from Michigan State University and a degree from Franklin Law School. He is a member of the bar.

Greg J. Williams is a program manager with the Transportation Association of Canada (TAC) in Ottawa. He joined TAC in 1988 as National Coordinator of the Canadian Strategic Highway Research Program. Previously he held numerous positions in the office of research and development of Alberta Transportation and Utilities. He holds a bachelor of science degree in civil engineering from the University of Alberta in Edmonton.