CHAPTER 9

PAVEMENT MANAGEMENT

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National Perspective on Pavement Management

FRANK BOTELHO

The nation's highway network represents a multibillion dollar investment that allows for the essential movement of people and goods.

Sound decisions on preventive maintenance, rehabilitation, and reconstruction of highway pavements are crucial to protecting that investment. For this reason, Pavement Management Systems (PMS) have become increasingly important and are now federally mandated on all Federal-aid highways. PMS provide valuable assistance to decision makers in determining cost-effective strategies for providing and maintaining pavements in serviceable condition.

History of PMS

Unlike other management systems that have begun in recent years, PMS were started two decades ago. Although they have made steady progress since that time, they are still new compared with other institutional functions such as planning, design, construction, maintenance, and research.

By the mid-1980s PMS were proving themselves and the benefits were being documented. By the end of the 1980s more than half the states were developing or implementing PMS. In 1989 the Federal Highway Administration (FHWA) issued a policy requiring all states to have a PMS that would cover principal arterials under the states' jurisdiction. It was therefore apparent to FHWA that a PMS was needed by all to ensure the cost-effective expenditure of Federal-aid funds.

The scope of federal and state involvement in PMS expanded when Congress passed the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) and required all states to have a PMS that covers all Federal-aid highways. The most significant aspect of this law was the expanded network coverage. FHWA's 1989 policy covered 313,700 centerline miles and ISTEA approximately tripled that coverage, increasing it to 916,200 centerline miles. This expanded coverage translates into a need for significant coordination among state and local governments. For example, of the total of 916,200 miles covered, 365,200 are under local jurisdiction.

In December 1993, FHWA issued a regulation covering all management systems. Section 500, Subpart B, of the regulation describes the ISTEA requirements for PMS. The following items are noteworthy:

1. The regulation is nonprescriptive;
2. Federal-aid funds are eligible for the development, implementation, and annual operation of a PMS;
3. States must develop their work plan by October 1994, designed to meet the implementation requirements;
4. Standards are included for the National Highway System (NHS);
5. The PMS for the NHS must be fully operational by October 1995;
6. The states have full flexibility to develop the standards for the PMS that cover the non-NHS routes;
7. The PMS for non-NHS routes must be fully operational by October 1997; and
8. PMS information must be used as input into the development of the metropolitan and statewide transportation plans and improvement programs.

Section 500.207, PMS Components, contains the components of a PMS for highways on NHS. There are three primary components: data collection, analyses, and update. The components under data collection include

1. *Inventory:* physical pavement features including the number of lanes, length, width, surface type, functional classification, and shoulder information;
2. *History:* project dates and types of construction, reconstruction, rehabilitation, and preventive maintenance;
3. *Condition survey:* roughness or ride, pavement distress, rutting, and surface friction;
4. *Traffic:* volume, vehicle type, and load data; and
5. *Data base:* compilation of all data files used in the PMS.

The components under analyses include

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1. *Condition analysis*: ride, distress, rutting, and surface friction;

2. *Performance analysis*: pavement performance analysis and an estimate of remaining service life;

3. *Investment analysis*: an estimate of network and project level investment strategies. These include single- and multi-year period analyses and should consider life-cycle cost evaluation;

4. *Engineering analysis*: evaluation of design, construction, rehabilitation, materials, mix designs, and maintenance; and

5. *Feedback analysis*: evaluation and updating of procedures and calibration of relationships using PMS performance data and current engineering criteria.

Advantages of PMS

A PMS involves a systematic approach that supplies quantifiable engineering information to help highway engineers and administrators manage highway pavements. The total decision-making process is based on information from PMS coupled with engineering experience, budget constraints, scheduling parameters, management prerogatives, public input, political considerations, and planning and programming factors.

The purpose of a PMS is to enhance the way an agency manages and engineers the preservation of its pavement network. A PMS brings to the table "condition data," the past, present, and predicted future condition of the pavement network. Coupled with inventory, project history, and cost data, a PMS can perform a myriad of engineering, management, and investment analyses.

A PMS helps provide the engineering justification for a multiyear network-level pavement preservation program. It can be used to measure the cost-effectiveness of the preservation program and in doing so it can determine the value added to the assets. When all the information in a PMS is analyzed (including key items such as the remaining service life), an agency can determine if it is meeting its own goals. Some basic questions a PMS should answer are

- Is the network in acceptable condition according to the agency's policy?
- Is the trend in condition staying the same, improving, or declining?
- Is there a backlog, and if so, how large is it?

A PMS should explore and seize opportunities to extend the service life of pavements—a major investment in the future of the nation's infrastructure. This goal can be accomplished by using the information in a PMS data base (i.e., performance data) to evaluate how well pavements are designed, constructed, and maintained. The quality of engineering and the materials used are of the utmost importance because these factors determine the rate at which pavements deteriorate. In general terms, a PMS should help accomplish work more efficiently and provide a way to measure how well it is carried out.

ISTEA requires that states have pavement management systems covering all Federal-aid highways, many of which are under local jurisdiction.

PMS Perspective

The following is an item-by-item perspective on current practices, future trends, and common hurdles in PMS.

Inventory

Most, if not all, states have an inventory of the physical features that are on the surface of the pavement (i.e., number of lanes, length, width, surface type, functional classification, and shoulder information). A number of states are lacking information on features that lie below the surface because of the time and expense involved in coring the pavement. The newest proven technology being used by the states to measure pavement layer thicknesses is ground-penetrating radar. When calibrated and using computer analysis, ground-penetrating radar can measure pavement layer thickness within plus or minus 5 percent for materials that have different dielectric constants. State-of-the-art equipment operates at highway speeds that makes it fast, safe, and cost-effective.

Project History

Most states do not have a complete project history (i.e., preventive maintenance, rehabilitation, and reconstruction data) for the NHS. Maintenance information is the weakest link. Most states have recently developed, or are in the process of developing, a PMS file for preventive maintenance activities. In cases for which it is impractical to resurrect the pavement history because of time, labor and cost, agencies are now beginning to track the project history.

Roughness

The technology for measuring pavement roughness at the network level generally began with response-type devices, followed by ultrasonic and visible optical devices. The future trend is toward infrared optical and laser profile devices.

Rutting

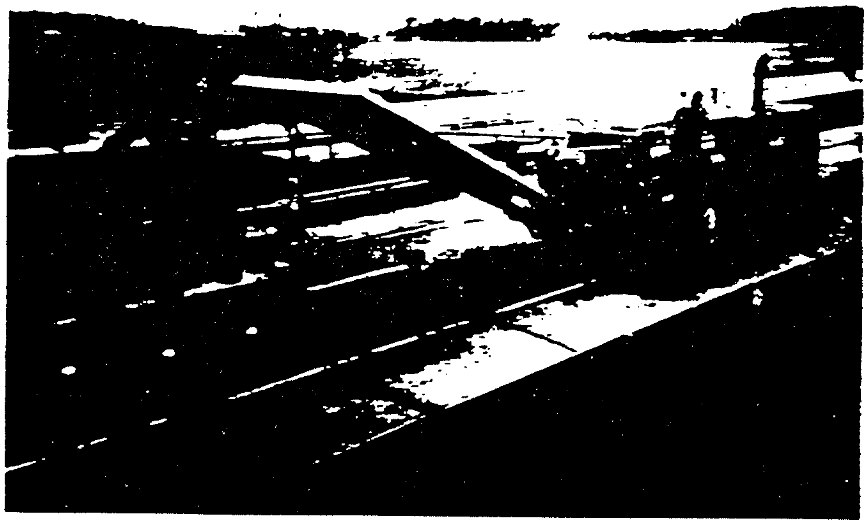
When PMS was first introduced 15 to 20 years ago, rutting was measured using straight edges and string lines. During the past 10 years, most state highway agencies (SHA) have acquired automated devices that measure rutting at highway speeds. These are typically ultrasonic devices with either three or five sensors. There are two other devices: one has 19 ultrasonic sensors and another has 11 lasers.

Cracking

In general, cracking is the distress that "drives" most PMS. For many years, cracks were measured using trained survey crews who walked or drove on the pavement. There are two types of driven surveys: slow and highway speeds (typically 40 to 50 mph). Currently, various SHAs use 35-mm film and super VHS video to photograph the surface of the pavement. The film and videos are then viewed on a monitor at an office workstation by a trained observer who performs the distress survey.

Viewing a film or video at an office workstation is safer and more convenient than conducting a walking field survey. However, pavement management engineers using walking surveys are able to detect more low-severity distresses than they can by watching a film or video survey because of its limited resolution.

A number of PMS engineers believe the optimum system is a fully automated approach that uses the science of pattern recognition. This type of system videotapes the pavement surface, enhances the images using gray scales and pattern recognition, and counts the cracks using computer software and algorithms. The obvious advantages of this type of system are high-speed data processing, safety, labor savings, and consistent data. Fully automated systems have now been developed, including one by the Texas Department of Transportation.



Pavement management systems provide valuable help in determining cost-effective strategies for providing and maintaining pavements in serviceable condition.

Structural Carrying Capacity

Only a handful of states are currently measuring the structural carrying capacity of their pavements at the network level using deflection measurements. Network-level measurements are not intended to have the same degree of accuracy as project design measurements. States that collect network-level data have shown them to be good general indicators of the overall carrying capacity of the network. These types of data and analysis can flag attention to special situations; for example when certain roads appear to have less carrying capacity than needed. Stationary deflection-measuring devices do not lend themselves to network-level PMS because the process is slow and costly. In the future, PMS will need a deflection-measuring device that operates at or near highway speeds. The deflection measurements obtained from a "rolling deflectometer," as it is known, and the pavement layer thicknesses obtained from the ground-penetrating radar, are used to compute the structural carrying capacity of the pavement.

Performance

Most states have the raw data needed to monitor and predict pavement performance, which is typically measured as condition or serviceability over a period of time. Currently half the states have performance curves, one-quarter are in the process of developing performance, and the remainder are not yet active. Excellent off-the-shelf software packages that PMS engineers can use for regression analysis are available. In the future, these software packages, coupled with today's high-speed and ever-more-powerful PCs, will enable PMS engineers to track and predict performance on a "route-specific" basis. This capability has already been proven and put into operation in at least some SHAs.

Traffic and Load Data

PMS need average daily traffic flow maps and equivalent single-axle load (ESAL) flow maps on a route-specific basis. Currently all SHAs have traffic flow maps. However, few SHAs have or can produce ESAL flow maps. Most traffic-collection procedures are geared toward collecting traffic volumes, which are primarily used by highway engineers and planners for capacity analysis. Until PMS came along, there was no need to collect traffic data for load analysis on a route-specific basis. Unfortunately for PMS engineers, collecting load data on a route-specific basis is more expensive than the existing traffic-collection process and it is not known if the additional expense (which has not been calculated for each state) is justifiable. More study is needed on this topic. Many PMS engineers and planners believe that better traffic- and load-prediction models are needed.

Ranking Projects

The backbone and heart of a PMS is its ability to rank in priority order pavement preservation projects that are justifiable and cost-effective. The most important phrase in the new (December 1993) FHWA regulation on management systems is the requirement that PMS for NHS produce "a prioritized list of recommended candidate projects with recommended preservation treatments that span single-year and multi-year periods using life-cycle cost analysis." Currently most state PMS do not produce a multiyear ranked list of projects with recommended treatments using life-cycle cost analysis, but are expected to have this capability in the future.

Remaining Service Life

Determining "remaining service life" is a requirement in the new regulation for NHS. Currently only 10 SHAs perform this analysis, but in the future it is anticipated that most will find this an unencumbered task. It is important to monitor the long-range health of a network and this analysis enables managers and programmers to maintain a "steady state" in their multiyear workload and budget.

Relational Data Base

A PMS cannot automatically, systematically, consistently, and efficiently function without a "relational data base" because the amount and complexity of data cannot be computed manually for a typical state PMS. Currently half the SHAs have relational data bases, one-quarter are developing them, and the remainder are not active at the present time. Given the state-of-the-art capabilities in relational data-base management systems, it is anticipated that most SHAs will have relational data bases in the near future.

Uniformity

Currently there is little-to-no uniformity among the states in the way they measure, collect, and report PMS condition data. The reason is that all states developed their PMS independently. This independence, of course, has many advantages for designing a PMS to meet the needs and objectives of any agency. But states are at a disadvantage when communicating with each other about basic condition information such as roughness, rutting, and cracking. They will find a lack of uniformity, which means that they cannot communicate or help each other to enhance this area of PMS. Efforts are under way and accomplishments have been made by ASTM and the Road Profiler Users Group (RPUG) that deserve commendation. The other management systems such as bridge and safety already have national standards for data collection and reporting.

PMS will benefit if the 50 states, Puerto Rico, and the District of Columbia agree to adopt more uniform methods to collect and report condition data. Future efforts by ASTM; RPUG; Strategic Highway Research Program, Long-Term Pavement Performance; FHWA; and the American Association of State Highway and Transportation Officials' Task Force on Pavements are aimed in that direction.

In-House and Outside Resources

Pavement management is a procedure that includes a wide variety of technical components. Some of these require a high degree of technical skill to develop and implement, whereas others require a high concentration of effort to establish. Each agency should carefully and objectively weigh its in-house capabilities, and if it does not have the resources, it should seriously consider seeking assistance from a consultant or a university. In the long run, it will save a lot of time and money and result in a better final product.

Staffing

The biggest problem the states face in developing, implementing, updating, and operating a PMS is staffing. There is a significant shortage of people who understand PMS. Once employees are trained and gain some experience, they are often promoted or transferred to other jobs. For the past five years, the annual turnover rate of state PMS engineers has been approximately 25 percent. The [illegible] incentives for early retirements have fueled that rate in the past two years. Generally, most SHAs have only one person who oversees the management and daily operation of the complete PMS program, and when that person leaves, most often the PMS shuts down. This situation occurs quite frequently and because of the current budget constraints and staffing ceilings in most highway agencies, it is not likely to improve. Unfortunately there is no quick fix to this problem.

Future Implementation of PMS

In gauging the future success of implementing PMS as called for in ISTEA, organizations must first decide whether they are serious about PMS. If so, and the commitment is made to do the work, supply the resources, and use the system, then PMS use is likely to be successful.

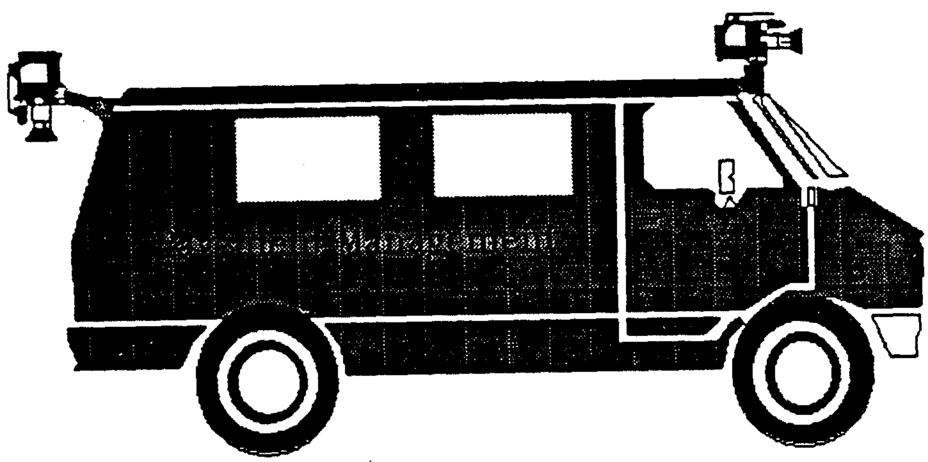
Students in the nation's colleges and universities will provide the life blood for PMS in the future. Currently 24 such institutions offer courses on PMS, but more are needed. FHWA and SHAs should support academia in providing more education about PMS and other management systems.

The largest institutional obstacle facing PMS today is acceptance by all managers and engineers in all agencies (including federal, state, and local). The reasons for this are many. The future holds more hard work for those who are serious about pavement management.

AUTOMATED PAVEMENT

CONDITON DATA

COLLECTION EQUIPMENT



Resource Paper

FHWA Pavement Division

July, 1989

NOTICE

This paper was prepared in the interest of technology sharing. It is not intended to be an all-inclusive discussion of the pavement data collection equipment available today.

Additional copies of this paper are available by contacting:

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PAVEMENT MANAGEMENT

Our nation's pavement network, much like the national population, is growing older. Resources to meet the needs of pavement preservation continue to fall short of existing needs, and the gap can be expected to widen as we approach the twenty-first century.

In order to address pavement needs, many agencies have turned toward a systematic process for Pavement Management. The AASHTO Guidelines on Pavement Management define Pavement Management as "the effective and efficient directing of the various activities involved in providing and sustaining pavements in a condition acceptable to the travelling public at the least life cycle cost." Simply stated, the purpose of Pavement Management is to get the most bang for the buck.

An effective Pavement Management System encompasses many of the disciplines within an agency's organization. These may include planning, programming, budgeting, data collection, design, type selection, construction, materials, research, maintenance, monitoring, and performance evaluation. The Pavement Management System draws from these disciplines, providing feedback to assess the adequacy of important decisions such as selected rehabilitation alternatives. Through the systematic Pavement Management System process, the individual disciplines may be constantly evaluated, refined, and improved.

In order to preserve pavements in a cost effective manner, the pavement condition for the agency's entire system, or network, must be known and periodically monitored. The condition of all pavements deteriorates with time and traffic loading (Figure 1).

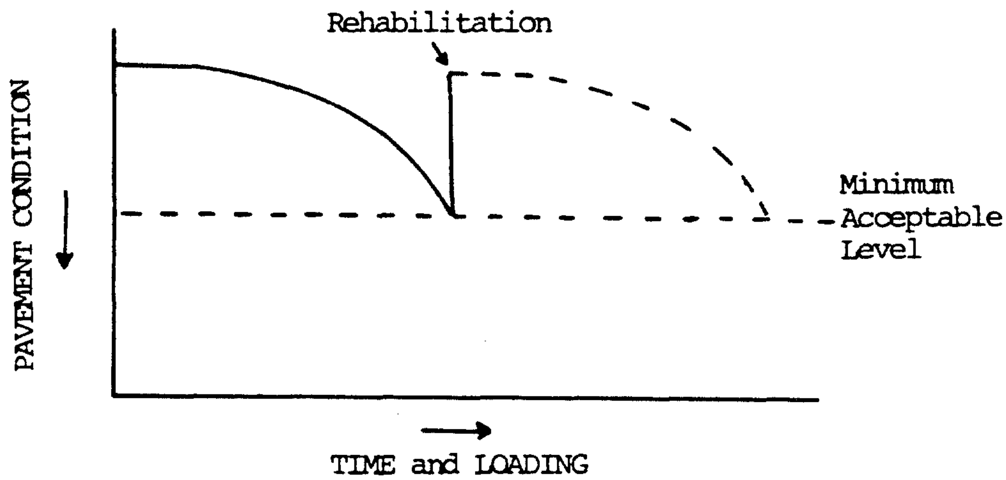


Figure 1 - Pavement Condition vs. Time and Loading

Following initial construction, pavement condition deteriorates slowly at first, then more rapidly as load applications are added. At some time after initial construction, the condition deteriorates to a minimum acceptable level at which time the pavement is rehabilitated. The condition is improved to a point above its minimum acceptable level, depending on the type and extent of the rehabilitation performed. This process continues indefinitely for every pavement section on the network at varying rates depending on variables such as design, construction, soils, materials, drainage, environment, loading, etc.

The minimum acceptable level varies depending on the classification of the pavement. For example, the minimum acceptable level for a heavily travelled Interstate facility can be expected to be considerably above the minimum acceptable level of a local service road.

If an agency is to make the most effective use of its scarce resources, then maintenance, rehabilitation, and reconstruction should be performed at the proper time (Figure 2). As the slope

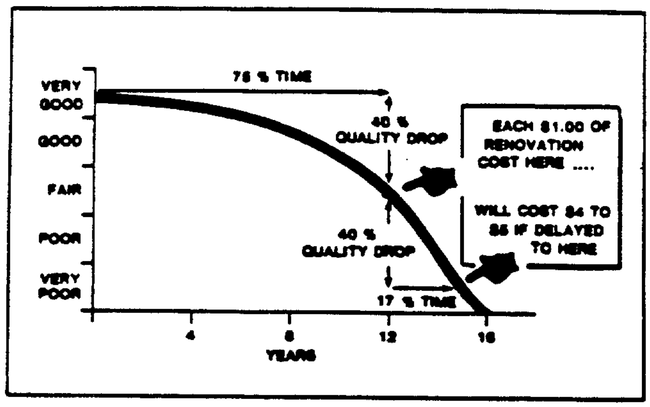


Figure 2 - Pavement Rehabilitation Cost vs. Time Performed

of the pavement deterioration curve changes from a horizontal line (zero) to a line approaching vertical (infinity), the incremental cost to repair an equal number of additional loads increases considerably. In a very short period of time the cost to rehabilitate the pavement to an equivalent level of serviceability may double, triple, or more.

Effective Pavement Management begins with the collection of the most reliable, consistent, and objective pavement condition data obtainable. The technological explosion of the past 10 years has permitted a tremendous improvement in the types, accuracy, repeatability, reliability, and degree of automation of available equipment to collect this data. Significant improvements are now being made annually, and can be expected to continue in the years ahead, especially in the area of automated crack detection technology.

CONDITION SURVEYS

Pavement condition data is collected by means of a condition survey. In past years, condition survey teams, made up of trained raters, walked or drove along the pavement and recorded observations of the pavement condition (Figure 3). On some networks, this technique is still in use.

Figure 3 - Condition Survey Team

Depending on the size of the network, one or more teams obtain the condition data. This data may be collected either for an entire network or statistically representative samples of the network. The productivity, accuracy, repeatability, reliability, and sampling intervals are related to the team's speed and the amount of data required. The limitation of this type of survey is its slow speed, the data collected is subjective and often varies from one observer to another, and the team members are exposed to traffic. Variations in the data collected inevitably result.

The use of high speed automated equipment is becoming more prevalent. While human observers are more versatile and creative than automated equipment, machines are fast, objective, tireless, consistent, and generally less disruptive to traffic because they travel at high speeds. Some State highway agencies (SHAs) have been moving toward automated pavement data acquisition. This trend is expected to increase in the years ahead.

AUTOMATED DATA COLLECTION

Most SHAs rely on four important pavement condition measurements to determine priorities for maintenance, rehabilitation, or reconstruction. These measurements generally include skid resistance, deflection, roughness, and distress. This paper provides an overview the state-of-the-art practice in automated data collection equipment.

The concept of automated collection of these and other desired data is not a new one. A roughness device was developed as early as 1923. The Bureau of Public Roads (now the Federal Highway Administration) standardized the BPR Roughometer, a devise to measure ride, in 1940. Automated procedures have been used to measure skid resistance since the 1940's, structural capacity since the 1950's, and distress since the early 1970's. New technology has been developed for various uses and is now being adapted to pavement evaluation. Examples are the use of non-contact transducers (sonic and ultrasonic probes, incandescent light, and lasers), ground penetrating radar, stress waves, still photography, thermal infrared photography, and video technology. Each of these areas is undergoing continuous change and constant improvement as more public and private funding is provided to develop the technology.

A SHA may realize cost and time savings through the proper selection and application of automated equipment for Pavement Management. Larger networks may realize greater savings by using automated devices. The most commonly used devices to collect skid, deflection, roughness, and distress data, and the equipment which may be seen in the future is described in the following sections. Appendix A contains a partial list of the commercially available equipment to collect pavement condition data.

Equipment for Skid Data Collection

Pavement skid resistance or surface friction is measured to evaluate pavement safety. Skid resistance varies with many factors such as pavement material, texture, aggregate type and amount of polish, temperature, type and amount of foreign material such as rubber, oil, grease, and dust on the pavement surface, water film thickness, and tire type, condition, inflation, tread pattern, and material composition.

Pavement skid resistance is usually measured directly through the use of locked wheel skid trailers. The trailer is towed over the pavement surface at a speed of 40 mph or higher and water is applied in front of the test wheel (Figure 4). The test wheel is

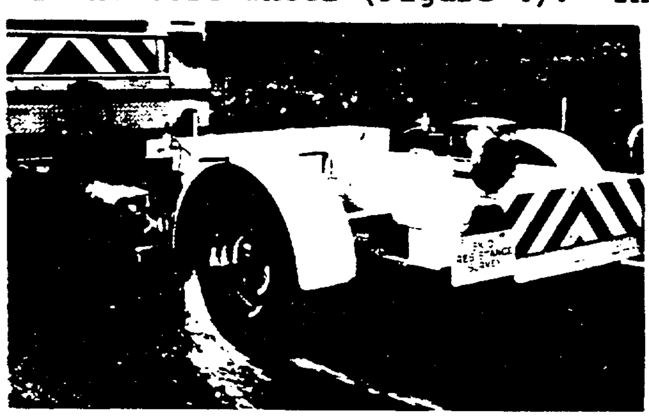


Figure 4 - Locked Wheel Skid Tester

locked by a brake, and after it has been sliding along the pavement for a certain distance the force that the friction in the tire contact patch produces or the resulting torque on the test wheel is measured and recorded for a specified length of time. Either a ribbed tire or a smooth tire can be used to perform the test. The ribbed tire is insensitive to the pavement macrotexture, allowing water dissipation through the tire grooves. The smooth tire is sensitive to the macrotexture.

Standard procedures (ASTM E 274-85) have been developed for the performance of skid testing with the locked wheel skid trailer. The result of the test is reported as a skid number. On-board computers are now being used to record and calculate the skid number, as well as to plot skid number versus speed, and peak incipient friction, if desired.

Another device available to measure skid resistance is the mu-meter (Figure 5).

Figure 5 - Mu-Meter

The mu-meter, like the locked wheel tester is trailer mounted. It uses smooth tires, yawed at equal but opposite angles to measure side friction force. Operation procedures are similar to the locked wheel trailer. On highway pavements the mu-meter may not provide an accurate indication of the pavement skid resistance due to the location of the narrowly spaced trailer wheels. The wheel paths of the mu-meter wheels generally fall between the normal wheelpaths of highway traffic. The use of the mu-meter has declined on highway pavements during the 1970's and 1980's.

New methods to improve testing efficiency and reduce skid testing costs are being studied. Recently completed research indicates that the spin-up tester may produce accurate results at lower costs. Like the locked wheel tester and mu-meter, this device is also trailer mounted. Testing begins following the locking of the wheels, and continues after the release of the brake until the wheels reach full angular velocity. The time interval between the moment the brake is released and the achievement of full angular velocity is indicative of the skid resistance of the pavement.

Automated equipment is now available and being refined to measure or correlate skid data indirectly with lasers and video technology. Two indirect methods to collect data for skid correlation are under development. Devises using laser sensors are capable of measuring the macrotexture of the pavement surface, which has some influence on skid resistance.

Video technology may also hold promise for the future, but has not yet been fully investigated in the United States for the purpose of correlation to skid resistance. A device known as the Yandell Mee Texture Friction Device is now in operation in Australia. The device uses a video camera, tracking device, and image enhancement to capture an enlarged video picture of the pavement surface. An on board computer collects the data. Software performs a statistical analysis of the texture, and produces output data on the locked wheel braking force friction and the sideways coefficient of friction.

Equipment for Deflection Data Collection

Measurement of pavement structural carrying capacity provides valuable data for the selection and design of a pavement rehabilitation strategy. Until recently, deflection was only collected and used at the project design level, but now several SHAs collect it at the network level, and the trend in this direction will probably continue.

Stronger pavements deflect less than weaker ones, and support far more traffic loadings. Deflection measurements are taken through the measurement of a deflection basin which is created by application of a load to the pavement. This load may be applied in several forms, such as by parking a loaded heavy vehicle of known axle loading, or by dropping masses onto the pavement surface. The load applied to the pavement surface creates a pavement deflection basin (Figure 6). The size, shape and depth of the deflection basin represents an overall system response of the paving layers and the subgrade to the known load. When the load is applied, all layers deflect creating strains and stresses in the supporting layers.

Differences in the size, shape, and depth of the deflection basin can be measured both at the surface and the underlying layers. Deflection will most often be measured at the pavement surface for network or project level analysis. On some research studies measurements may be taken at various depths in the pavement section, such as at the asphalt-aggregate interface, and the bottom of the subgrade.

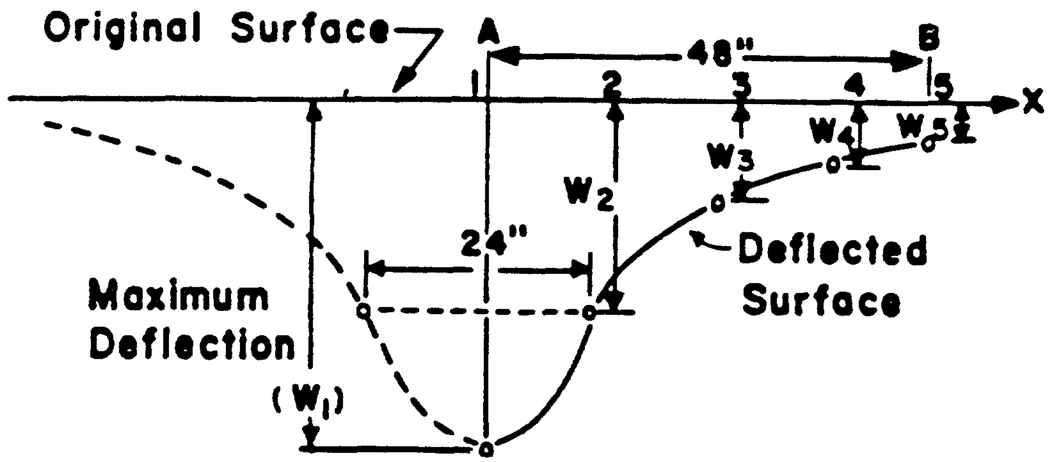


Figure 6 - Typical pavement deflection basin

Many factors influence the measured pavement deflection and interpretation of the results requires a thorough analysis. As the load is increased the pavement deflection will also increase, but not linearly, since most pavement material properties are stress dependent. Factors influencing the measured deflection include the pavement type, stiffness of the pavement/subgrade system, location of the test, proximity to joints or cracks, location of drainage structures, variations in soil composition and moisture, and voids beneath the pavement structure. Climatic factors such as temperature, thermal gradients, moisture, and depth of frost greatly affect the results, as does the season of the year in which the tests are taken. All deflection data should be adjusted to a constant temperature and season prior to plotting or use. Proper procedures must be followed for temperature and seasonal corrections to obtain reliable results.

Four classes of equipment exist to measure deflection: static deflection equipment, automated beam deflection equipment, steady-state dynamic deflection equipment, and impulse deflection equipment.

Static deflection equipment

Static deflection equipment is used to measure the deflection of the pavement to slowly applied loads. The most commonly used static deflection device is the Benkelman Beam, a 12-foot beam pivoted at the third point. The pivot provides an 8-foot probe with the extreme tip resting on the pavement and supported by the pivot point. The rear end is a 4-foot cantilever beam which moves upward when the pavement deflects downward. The basic components are depicted in Figure 7.

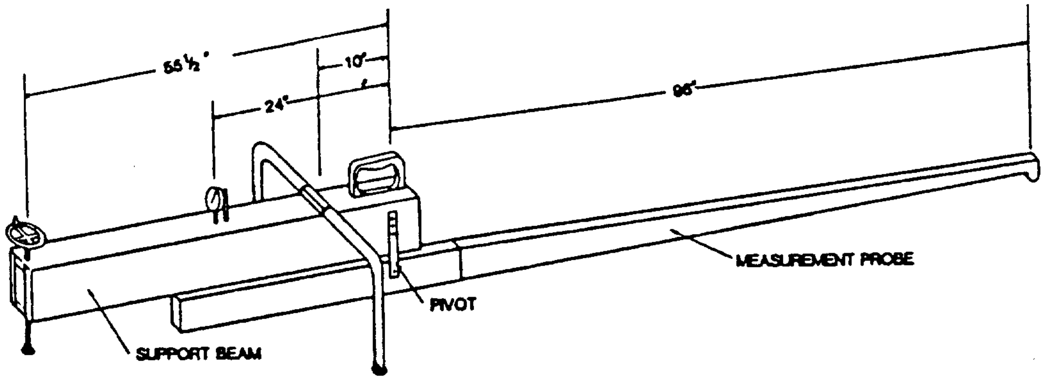


Figure 7 - Basic Components of the Benkelman Beam

The device uses a loaded truck to create the deflection. A dial indicator rests on the rear end and measures this movement. The only measurement recorded with the Benkelman Beam is the maximum rebound deflection. The limitations of the device are insuring that the front supports are not located within the deflection basin, the inability to determine the shape and size of the basin, and poor repeatability of the results. Due to these limitations the SHAs are moving away from the static devices and toward other types such as the impulse deflection equipment.

Other devices in this category are the Curvature Meter and the Plate Bearing Test equipment.

Automated Beam Deflection Equipment

Equipment which automates the Benkelman Beam process is placed in this class. Included is the La Croix Deflectograph which has been used widely in Europe and other parts of the world, and the Travelling Deflectometer which is used by the California Department of Transportation.

Steady-State Dynamic Deflection Equipment

Steady-state dynamic deflection devices place a static preload on the pavement surface. A steady-state sinusoidal vibration is then induced in the pavement with a dynamic force generator. The advantage of this type of equipment over static equipment is that a reference point is not needed. An inertial reference is used and the change in deflection can be compared directly to the magnitude of the dynamic force. One of the limitations of this type of equipment is the use of the static preload. This load is relatively large in comparison with the maximum peak to peak loading. The most commonly used steady-state dynamic deflection devices are the Dynaflect and the Road Rater.

Dynaflect - The Dynaflect (Figure 8) was one of the first commercially available steady-state dynamic deflection devices. It is trailer mounted, and can be towed by a standard automobile.

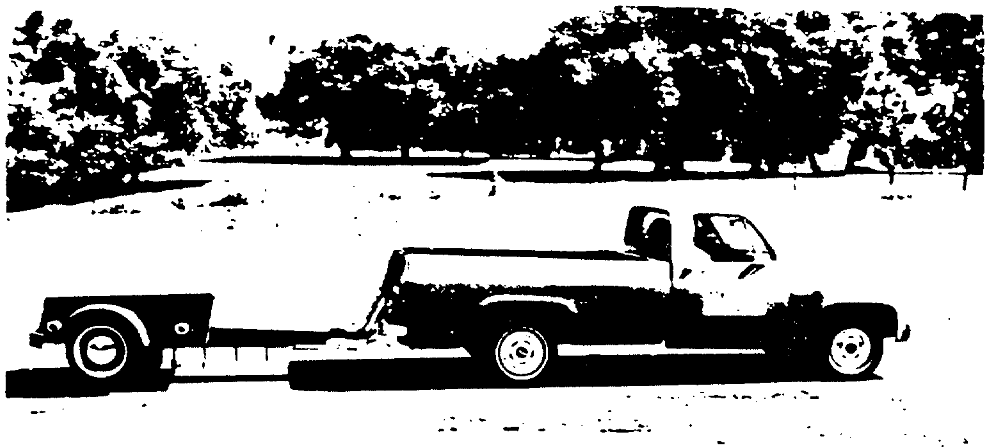


Figure 8 - Dynaflect

The Dynaflect applies a static weight of 2000 to 2100 pounds to the pavement while the dynamic force generator produces a 1000-pound peak-to-peak force. Deflection is measured using five velocity transducers (geophones). The transducers are suspended from a placing bar which is normally placed in the center of the loaded area and at one-foot intervals away from the load (Figure 9).

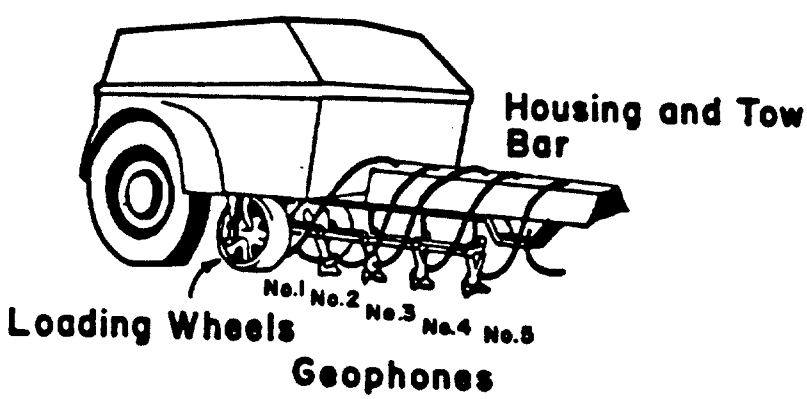


Figure 9 - Schematic of the Dynaflect in testing position

The device is moved to the test point and the loading wheels and geophones are hydraulically lowered to the pavement surface. The device is then moved to the next site on the loading wheels. The limitations of the Dynaflect are the maximum peak-to-peak loading, which is limited to 1000 pounds, the inability to vary the load, and the fixed frequency of the loading, which cannot be changed.

Due to this limitation this device may be inadequate to evaluate thick pavement sections and other devices with heavier loading systems should be considered.

Road Rater - The Road Rater (Figure 10) is the second type of

Figure 10 - Road Rater

commercially available steady-state dynamic deflection device. Three models, which vary in the magnitude of the applied load are available. The static load is applied to the pavement surface through a steel plate. The dynamic force generator produces a peak-to-peak force which is one-half the magnitude of the static preload. The amplitude and the frequency can be altered. This allows different dynamic peak-to-peak loadings ranging from 1000 to 8000 pounds. The loading frequency can be varied between 5 and 70 cycles per second. Three sensors are attached to an arm trailing the loading plate, with an additional sensor in the center of the loaded area.

Testing starts by moving the device to the test point, and lowering the test plate and the sensors to the pavement surface. A test run is performed at selected loads and frequencies, the loading plate and sensors are lifted from the surface, and the device is moved to the next site. The limitations of this device is the limited load level for the lighter models, and the requirement for a heavy static preload for the heavier models.

Other Steady State Deflection Equipment - Other devices in this category include the FHWA Thumper, a custom-built device that can perform static, dynamic, or intermittent pulse loading, and other custom-designed dynamic deflection devices.

Impulse Deflection Equipment

These devices deliver a transient force impulse to the pavement surface. They use a weight which is lifted to a specified height on a guide system, and dropped. The falling weight strikes a plate, which transmits the force to the pavement. By varying the amount of weight and the drop height, the impulse force can be varied.

The advantage of the impulse type equipment is the ability to model a moving wheel load in both magnitude and duration. The resulting deflection closely simulates deflections caused by a moving wheel load. The impulse equipment has a relatively small preload compared to the actual loadings. The preload prior to releasing the weights varies with the equipment. It is usually in the range of 8 to 18 percent of the maximum impulse load which is 9,000 to 24,000 pounds. The preload during the period the weights are dropping is normally in the range of 5 to 14 percent of those same maximum impulse loads.

Dynatest Falling Weight Deflectometer - The most widely used falling weight deflectometer (FWD) in the U.S. is the Dynatest model 8000 FWD (Figure 11). The system is trailer mounted and can

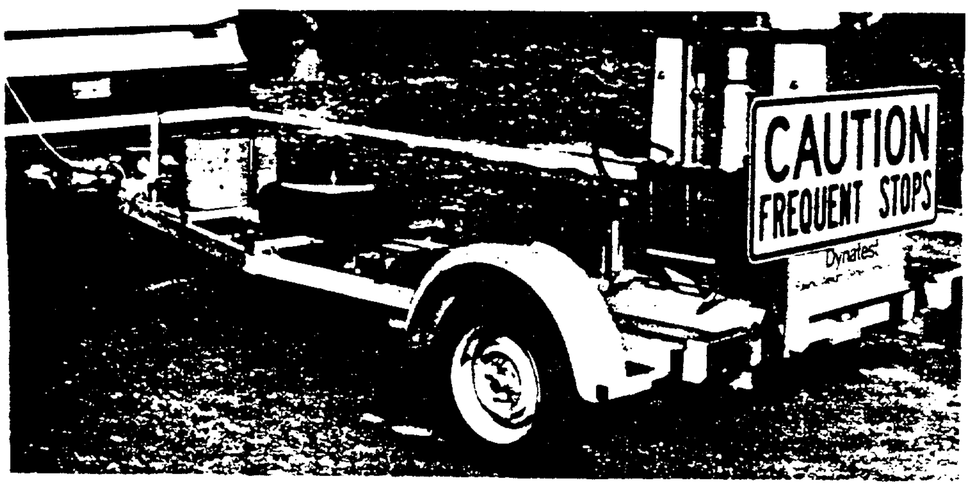


Figure 11 - Dynatest Falling Weight Deflectometer

be towed by a van or pickup truck. Its impulse force is created by dropping weights from different heights. By varying the drop height and weights, a force range of 1,500 to 24,000 pounds can be developed. The load is transmitted through a rubber buffer system and an 11.8 inch diameter loading plate to the pavement. The deflection basin is measured using up to seven velocity transducers which are mounted on a bar and lowered with the loading plate to the pavement surface. The device is moved to the test site, and the loading plate and transducers are lowered to the pavement. A test sequence is completed using a number of drops at each selected drop height. The loading plate and sensors are then hydraulically lifted, and the FWD is moved to the next site.

Other Impulse Deflection Equipment - Other devices in this category include the KUAB and the Phoenix FWDs. Both are trailer mounted and are operated in a similar manner to the Dynatest FWD, using various combinations of number and size of weights and drop heights.

A summary of the most commonly used deflection devices and their various measurement properties and features is contained in Table 1. The most important limitation of current deflection equipment is the inability to collect the data at high speeds. Stops must be made at each test location, requiring the maintenance of traffic. Developmental efforts are underway to automate deflection equipment to reduce traffic conflicts. Again, it should be emphasized that pavement deflection data should be used carefully. Appropriate correction factors for temperature, moisture, time of season, test location, etc. must be applied in order to produce meaningful data. Proper use of this very important data can yield effective information for the design of pavement rehabilitation strategies.

TABLE 1 - DEFLECTION EQUIPMENT

DEFLECTION DEVICE	PRINCIPAL OF OPERATION	LOAD ACTUATOR SYSTEM	STATIC WE[illegible]T ON PLAT[illegible]	TYPE OF LOAD TRANSMISSION	RELATIVE COST	DEFLECTION MEASURING SYSTEM	NUMBER OF SENSORS
Benkelman Beam	Deflection Beam	Loaded Truck Axle	N/A	Truck Wheels	Ext. Low	Dial Indicator	1
Dynaflect	Steady State Vibratory	Counter Rotating Masses	2100	Two UrethaneCoated Steel Wheels	Low	Velocity Transducers	5
Road Rater	Steady State Vibratory	Hydraulic Actuated Masses	*2,400 to 5,800 lbs.	*Two rectangular or 1 round plate	Low-Medium	Velocity Transducers	4
KUAB FWD	Impulse	Two Dropping Masses	N/A	Round Plate	Medium	Seismic Deflection Transducers	5
Dynatest 8000 FWD	Impulse	Dropping Masses	N/A	Round Plate	Medium-High	Velocity Transducers	7
La Croix Deflectograph	Mechanized Deflection Beam	Moving Weighted Truck	N/A	Truck Wheels	Ext. High	Inductive Displacement Transducers	2

Equipment for Roughness Data Collection

Over a period of time all pavement surfaces become increasingly rough. Ride quality, a subjective evaluation of pavement roughness, may be evaluated through the use of rating panels (which may be part of the condition survey team), or through the use of manually operated or automated equipment. Other equipment may be used to objectively measure roughness. In terms of pavement profile, roughness can be defined as the summation of variations in the surface profile of the pavement. This pavement roughness consists of surface irregularities with wavelengths and amplitudes ranging from fractions of an inch to several feet. The measurement of pavement roughness corresponds to the measurement of the actual pavement profile or the measurement of the response of a mechanical system to the profile.

Knowledge of the extent of pavement roughness is essential since roughness often provides some indication of a pavement's need for maintenance, rehabilitation, or reconstruction. Roughness is also one of the primary criteria by which the public measures the credibility of an agency that manages pavements. FHWA considers roughness data collection to be of vital importance in the assessment of pavement condition. The States will be required to have automated calibrated equipment operational for the collection of Highway Performance Monitoring System data by the end of 1989.

Equipment for roughness survey data collection may be broadly categorized into 4 categories, the relative degree of automation and complexity of which increases in the order listed:

- Rod and level survey-including the Dipstick Profiler,
- Profilographs,
- Response type road roughness meters (RTRRMs),
- Profiling Devices

Each category has its advantages and limitations, and selection of appropriate roughness equipment should be made following a careful assessment of the primary purpose for which the equipment is to be used, and an analysis of the advantages and limitations of each device. One of the most important considerations in selection of a roughness measuring device is the tradeoff between the relatively low initial and data collection costs of devices such as an RTRRM, versus the frequent need to calibrate the device. Other tradeoffs must also be carefully considered.

Laser devices may also be used to measure pavement roughness. Since the laser can also be used to measure other pavement parameters, its use will be discussed in the section "Equipment for Distress Data Collection".

Rod and Level Survey and the Dipstick Profiler

Rod and level surveys provide an accurate measurement of the pavement profile. The use of the rod and level survey for network or even large project survey data however, is impractical and cost prohibitive. A first-step automation of the rod and level survey which may be used to collect a relatively small quantity of pavement profile measurements is through the use of the Dipstick Profiler (Figure 12).

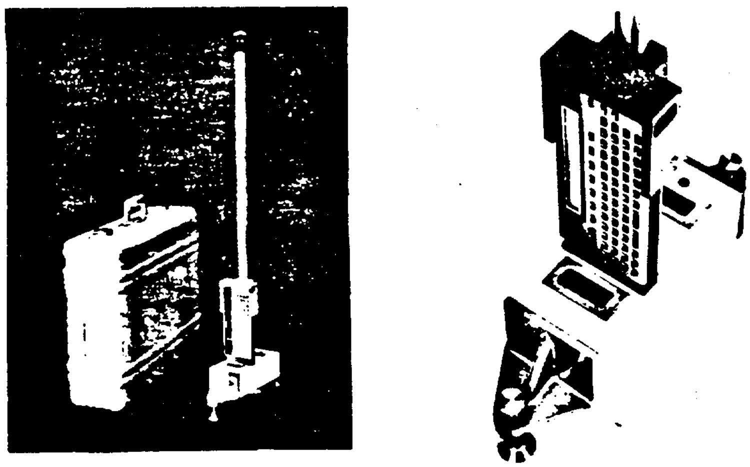


Figure 12 - The Dipstick Profiler

The Dipstick Profiler consists of an inclinometer enclosed in a case supported by two legs separated by 12 inches. Two digital displays are provided, one at each end of the instrument. Each display reads the elevation of the leg at its end relative to the elevation of the other leg. The operator then "walks" the dipstick down a premarked pavement section by alternately pivoting the instrument about each leg. Readings are recorded sequentially as the operator traverses the section. The device records 10 to 15 readings per minute. Software analysis provides a profile accurate to plus or minus 0.005 inch.

A common application for the dipstick is to measure the profile for the calibration of RTRRMs. A strip can be surveyed by a single operator in about one half the time of a traditional survey crew.

Profilographs

Profilographs have been available for many years and exist in a variety of different forms, configurations, and brands. Due to the design they are not suitable for condition surveys. Their most common use today is for portland cement concrete pavement construction inspection, control, and acceptance. The major differences among the various profilographs involve the configuration of the wheels and the operation and measurement procedures of the various devices.

Profilographs have a sensing wheel, mounted to provide for free vertical movement at the center of the frame (Figure 13). The

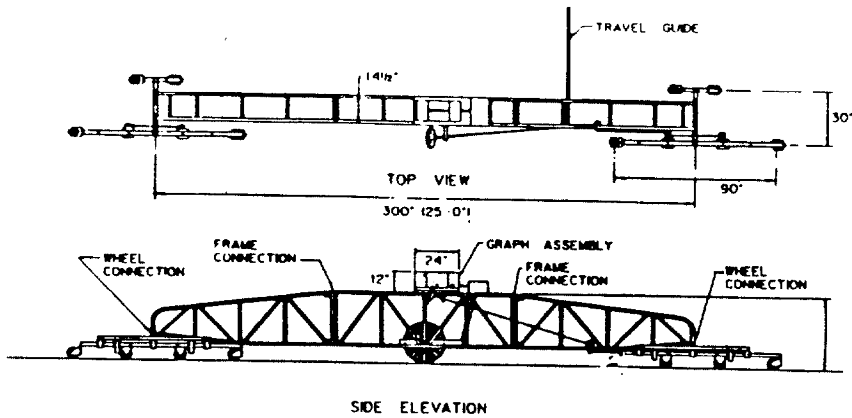


Figure 13 - Profilograph Layout (California type Profilograph)

deviations against a reference plane, established from the profilograph frame, is recorded (automatically on some models) on graph paper from the motion of the sensing wheel. Profilographs can detect very slight surface deviations or undulations up to about 20 feet in length.

Response Type Road Roughness Meters

The third category of roughness data collection equipment is the response type road roughness meters. This category includes such devices as the BPR Roughometer (Figure 14), the Mays Ride Meter (Figure 15), and the PCA Road Meter. RTRRMs have been used for a

Figure 14 - BPR Roughometer

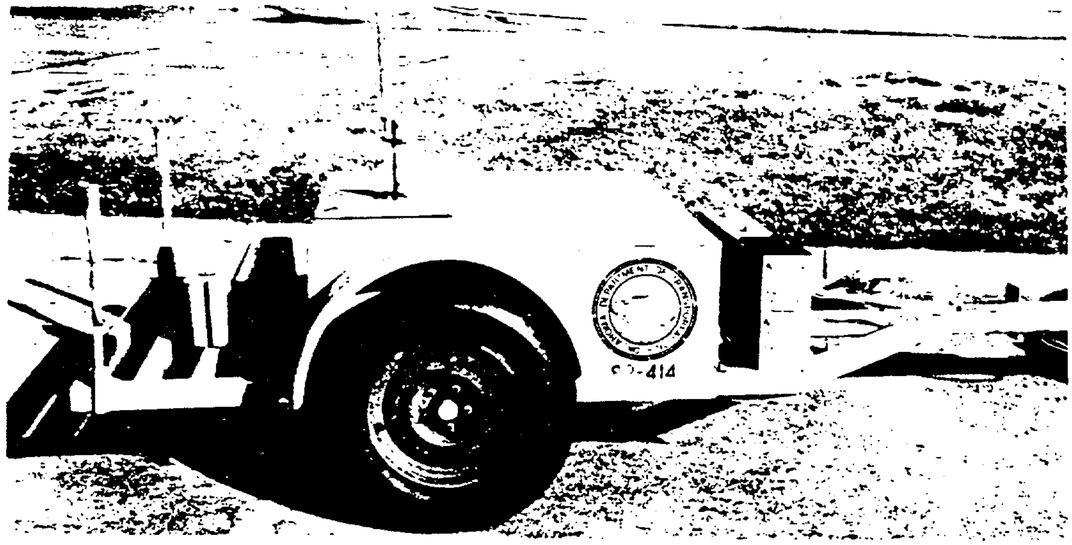


Figure 15 - Mays Ride Meter

number of years and are currently the most widely used roughness data collection device in the United States. Their primary use is for network level roughness data collection.

Road meters or RTRRMs measure the vertical movements of the rear axle of an automobile or the axle of a trailer relative to the vehicle frame. The meters are installed in vehicles with a displacement transducer on the body located between the middle of the axle and the body of a passenger car or trailer. The transducer detects small increments of axle movement relative to the vehicle body. The output data consists of a strip chart plot of the actual axle body movement versus the time of travel.

The advantages associated with the use of RTRRMs are:

- The initial and operating costs are low.
- Reasonably accurate roughness data is provided if the device is properly calibrated.
- Reproducible results may be obtained when the device is properly maintained.
- Data can be collected at high speeds, i.e. 50 mph.
- Efficiency--numerous pavement sections can be evaluated in a relatively short period of time.

In spite of the advantages of RTRRMs, there also several limitations:

- Response type equipment records the dynamic response of a mechanical system travelling over a pavement at a constant speed. Therefore, the characteristics of the mechanical system and speed of travel affect the measurement.

* RTRRMs measure a dynamic effect of the roughness but do not define the profile of the pavement.
* In order to provide accurate, consistent and repeatable data, the device must be frequently calibrated, through a range of operating speeds, against sections of known profile, ranging from very smooth to very rough. The annual costs of the calibration checks can be quite high.
* The vehicles in which the RTRRMs are installed contribute many potential sources of variation including rear suspension damping, tire nonuniformities and inflation pressure differences, and vehicle weight changes.
* Due to the variations of the various mechanical systems of RTRRMs, comparability of data among users with the same user, or with the same device is difficult, unless a common standard roughness index is used.

Several standard calibration procedures have been developed for the RTRRMs which are in use today. Careful operating and maintenance procedures should be followed, including frequent and precise calibrations, in order to improve device accuracy and consistency. The degree of accuracy desired in the calibration of RTRRMs ultimately depends upon the proposed use of the data being collected.

RTRRM systems are adequate for routine monitoring of a pavement network and providing an overall picture of the condition of the network. The output can provide managers with a general indication of the overall network condition and maintenance needs.

Profiling Devices

Profiling Devices are used to provide accurate, scaled, and complete reproductions of the pavement profile within a certain range. They are available in several forms, and can be used for calibration of the RTRRMs. The equipment is expensive, with complexity increasing depending on the types and number of transducer sensors contained on board. Three generic types of profiling systems are in use today:

* Straight edge
* Low speed systems
* Inertial Reference Systems

The simplest profiling system is the straight edge. Modifications to the straight edge, such as mounting it on a wheel are very popular (profilographs). Low speed systems such as the CHLOE profilometer (Figure 16) are moving reference planes that have little or no dynamic effect due to their low speed. The CHLOE is a long trailer that is towed at low speeds of 2 to 5 mph. The slow speed is necessary to prevent any dynamic response measurement during the readings. The device measures the

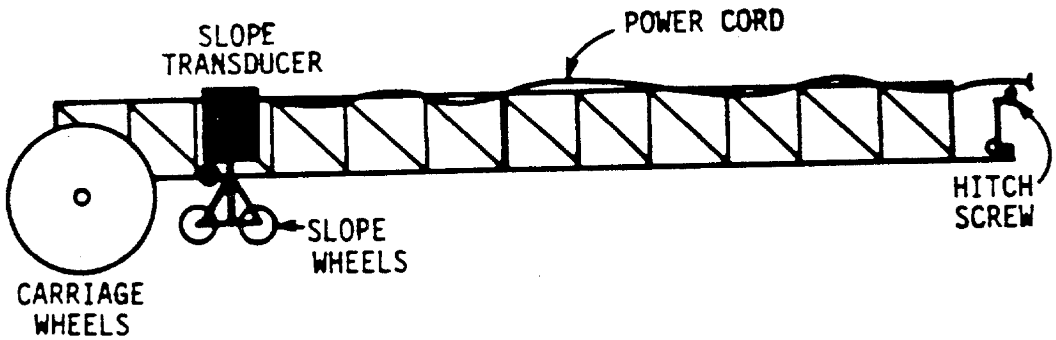


Figure 16 - CHLOE Profilometer

difference in slope between a small arm with two wheels and a trailer frame with 2 larger wheels. A few agencies still use the CHLOE to calibrate their RTRRMs.

Most sophisticated road profiling equipment uses the inertial reference system. The profiling device measures and computes longitudinal profile through the creation of an inertial reference by using accelerometers placed on the body of the measuring vehicle to measure the vehicle body motion. The relative displacement between the accelerometer and the pavement profile is measured with either a "contact" or a "non-contact" sensor system.

The earliest profiling devices used the contact system to measure the profile. The contact system uses a mechanism in direct contact with the pavement. Several contact systems have been used, and are still in use today. The French Road Research Laboratory developed the Longitudinal Profile Analyzer (APL) in 1968 (Figure 17).

Figure 17 - Longitudinal Profile Analyzer

The APL consists of a specially designed single-wheel trailer and electronic data and measurement monitoring equipment. The trailer is pulled at a constant speed by a towing vehicle which contains the electronic equipment. The APL measures pavement profile based on the amplitude of the vertical movements of the follower wheel. These movements are measured in relation to a horizontal reference pendulum (Figure 18). As the follower wheel travels over the

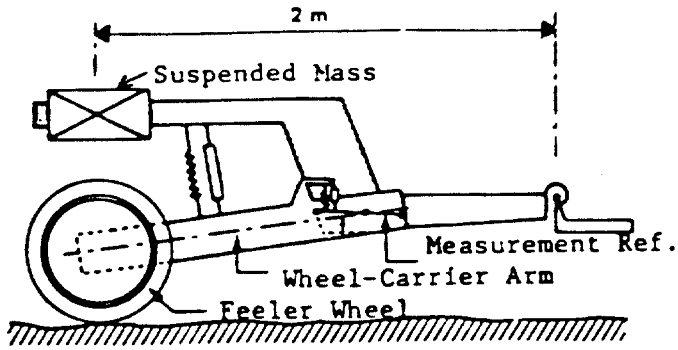


Figure 18 - Longitudinal Profile Analyzer Measurement System

pavement surface the change in the angle between the trailing arm or rocking shaft and the horizontal pendulum is processed by the system software into a profile value.

Systems used today in the United States are frequently installed in vans which contain on board microcomputers and other data handling and processing instrumentation. Older profiling devices are usually contact systems, while the more recently manufactured devices use non-contact sensors. A contact system is depicted in Figure 19. This system uses a small tracking wheel which

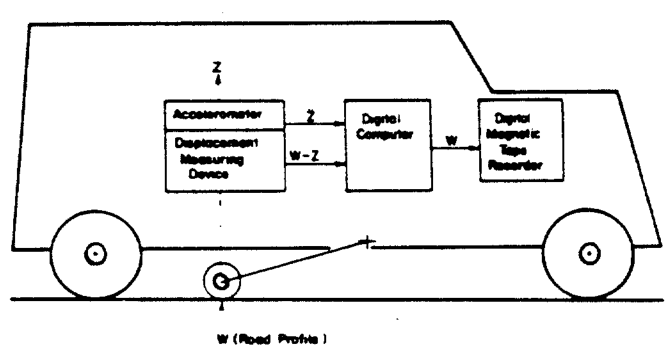


Figure 19 - Contact Profiling Device

measures the surface of the pavement. The mechanical systems experience maintenance problems related to wearing and operation of the wheel. Recently constructed systems use non-contact probes, either acoustic or light, to measure differences in the pavement surface.

Both measure and compute the longitudinal profile through the creation of an inertial reference plane. An accelerometer, placed on the body of the measuring vehicle, measures the vehicle body motion. The relative displacement between the accelerometers and the pavement profile is measured with the non-contact light beam mounted with the accelerometer on the vehicle body. The sensor beam is projected vertically down on the pavement to create a light "foot print".

Displacement between the vehicle and the pavement surface is determined by measuring the angle at which the light beam footprint is viewed by part of the system mounted under the vehicle and just ahead of the light beam footprint (Figure 20).

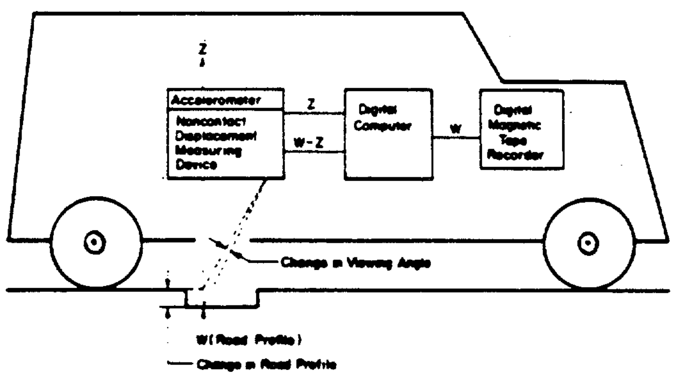


Figure 20 - Principle of Operation of a Non-contact Profiling Device

As the pavement surface profile varies, the distance between the vehicle and the pavement surface changes, and the angle at which the footprint is viewed also changes. Through the geometry of the system, this measured angle can be converted to a measured displacement and used in computation of the profile. Distance measurements of the position of the vehicle are simultaneously recorded in fractions of a foot as the vehicle travels along the roadway. The profile is computed as a function of distance travelled by an on board digital computer and is saved and stored for later use.

Profiling devices are capable of providing highly accurate roughness data and scaled reproductions of the pavement profile. A summary of the most commonly used roughness data collection devices, their measurement principles, relative costs, relative degrees of accuracy, and current and projected future use is contained in Table 2.

TABLE 2 - ROUGHNESS DATA COLLECTION EQUIPMENT

ROUGHNESS DATA COLLECTION DEVICE	PRINCIPAL OF MEASUREMENT	RELATIVE INITIAL COST	RELATIVE DATA COLLECTION COST (NETWORK)	RELATIVE DEGREE OF ACCURACY	APPROXIMATE NUMBER OF YEARS IN USE	EXTENT OF CURRENT USE	PROJECTED EXTENT OF USE YR. 1990-2000
Dipstick	Direct differential Measurement	Low	Impractical	Very High	8	Limited, used for Calibration	Same as Current Use
Profilographs	Direct Profile Recordation	Low	Impractical	Medium	30	Extensive for Const. Accptance	Same as Current Use
BPR Roughometer	Device Response	Low	Low	Medium	50	Limited	None
Mays Meter	Vehicle Response	Low	Low	Medium	30	Extensive	Decreasing Continuously
South Dakota Road Profiler	Direct Profile Recordation	Medium	Low	High	7	Growing	Rapidly Increasing
Contact Profiling Device	Direct Profile Recordation	High	Medium	Very High	20	Limited	Decreasing
Non-Contact Profiling Device	Direct Profile Recordation	Very High	Medium	Very High	8	Medium	Increasing Continuously

PAVEMENT DISTRESS

By far the greatest number of innovations and inventions in the past 10 years have come in the area of distress data collection equipment. Devices may soon be available which automatically collect and reproduce pavement distress information in a form acceptable for use during pavement rehabilitation -- but we're not to this point yet.

Before examining equipment available to collect pavement distress data, we must first stop and try to answer the question "What is pavement distress?" As elementary as this question may seem, it has been surprisingly difficult to answer in the past. First, the pavement type must be known -- is it jointed plain concrete, jointed reinforced concrete, continuously reinforced concrete, prestressed concrete, asphalt, an asphalt overlay of the various types of portland cement concrete, one of the various types of portland cement concrete over asphalt, portland cement concrete over portland cement concrete, bonded, unbonded, asphalt over asphalt, etc. What type of base exists, granular, stabilized, free-draining, etc? What measurement criteria was used? What type of distress was noted, what was its extent, and what was its severity? Each question may generate several others.

Many types of distress have been identified for stabilized pavement surfaces. Methods have been devised by various agencies to standardize distress classifications and to automate the recording, reduction, processing, and storage of the data. Condition survey manuals which define classifications using photos and descriptions have been used to minimize discrepancies between raters. One document which best answers many of the questions about highway pavement distress is the "Highway Pavement Distress Identification Manual for Highway Condition and Quality of Construction Survey". This manual describes 17 or more pavement distress types for each pavement type. Some procedures use detailed measurements of the distress to minimize errors.

To simplify this discussion, distress types will be limited to two very general categories for asphalt pavements -- rutting and cracking, and one category for PCC pavements -- cracking. Extent and severity may be dealt with in relative terms. For the extent, the percentage of the pavement distressed versus the total pavement length or area surveyed can be used. Severity can also be handled in relative terms -- light, medium, and heavy. Numerical parameters can be assigned at a SHAs discretion in order to classify the distress by extent and severity.

Equipment for Distress Data Collection

The thankless job of collecting pavement distress data by visual survey is being simplified through the use of current technology.

Condition survey teams now have at their disposal numerous means and devices to collect distress data. This list of available devices is growing each year, and more fully automated processes are being designed and implemented. Automation of pavement distress data collection may be categorized into five levels of automation:

- Improved subjective rating through data entry with condition rating keyboards or voice activated systems,
- Acoustic systems,
- Laser technology
- Partial objective automation through evaluation of photographic records, and
- Fully automated processing through digitized reduction (or other fully automated methods) of video or other collected images.

Condition Rating Keyboards

The first degree of automation is by data entry with a hand held computer or data logger. The operator uses a keyboard similar to an office personal computer keyboard, or another design, to input observed distress types, extents and severities (Figure 21). The

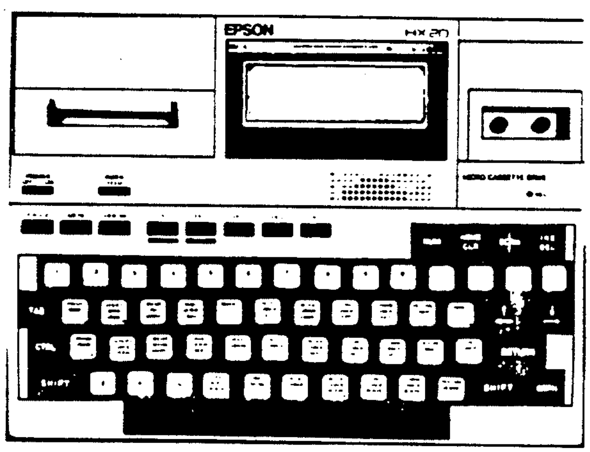


Figure 21 - Condition Rating Keyboard

keyboard may be pre-programmed prior to beginning the condition survey, based on a preliminary assessment of the existing distress, or through knowledge of the most commonly encountered distress types. A distance measuring instrument continuously tracks the location of the vehicle, and interfaces with the data input to define the location of the recorded distress. Information collected is stored on a hand held or personal computer installed in the vehicle, then down loaded to an office computer.

Voice Activated Systems

One new technology now being employed on a more limited basis is the use of a voice activated system. This system provides a significant advantage over the keyboard since it frees the hands of the operator. While at least two raters are required for the condition keyboard system, the voice activated system requires just one rater. The rater speaks into a microphone attached to a headset, and using a voice controlled microprocessor, the information is coded with the location and stored on the computer in the vehicle. A sound track recording is produced which may be used with recorded video information, if used. Depending on the software, the system may recognize several hundred standard condition observations stored in the system.

Acoustic Devices

Sonic and ultrasonic probes are now being used to a great extent, to measure profile and rutting. The probes are used as displacement transducers, measuring the distance to the pavement surface from an established inertial reference plane of the vehicle. Any number of transducers may be mounted on the vehicle or on a bar attached to the vehicle to measure rutting (Figure 22). The probes generate a short burst of sound waves

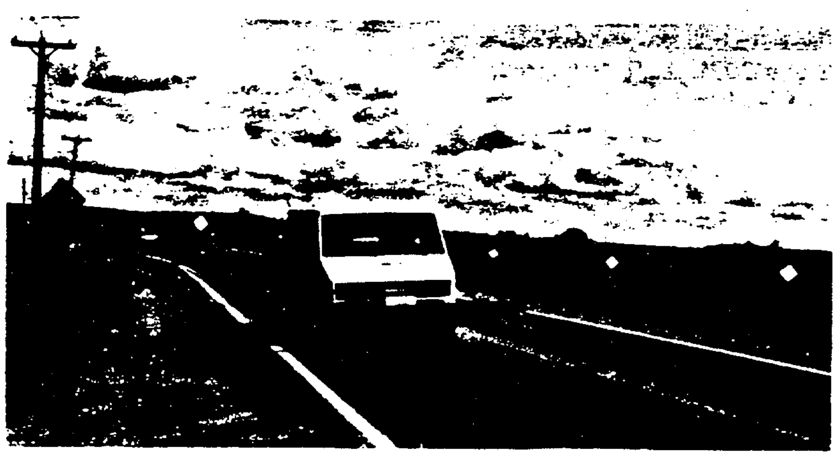


Figure 22 - Survey Vehicle with a Rut Bar

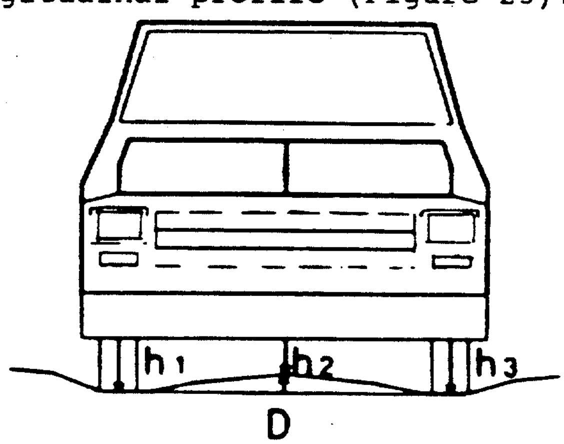
which travel to the pavement surface and are reflected back to the transducer. The elapsed time between the sound generation and the echo detection is proportional to the distance travelled. The number of transducers selected should correspond to the level of detail required. For network level surveys, 3 to 5 points usually provide an adequate transverse profile. Vehicles have been manufactured with up to 37 transducers to provide an accurate cross section of a 12 foot width of pavement.

The sensors should be used only when the pavement surface is dry, as the sensors themselves, and the readings may be adversely affected by moisture. Sound travels comparatively slowly, (about 1125 feet per second through air) therefore the speed of the survey vehicle has some minor effect on the measurement. Since the speed of sound is also dependent upon the density and temperature of the medium through which it travels, air temperature also affects readings. These effects, however, are minimal for network level surveys.

The South Dakota DOT (SD DOT) has developed a system, known as the South Dakota Road Profiler, which uses an ultrasonic transducer, accelerometer, and an on board computer system to measure, process and store pavement profile data. A number of other SHAs are also presently considering manufacture of a system similar to the one developed by the SD DOT. This system uses an ultrasonic probe as a displacement transducer. The probe is mounted on the front of the vehicle and measures the distance from the vehicle to the pavement surface from an established inertial reference plane. An accelerometer, mounted near the acoustic probe, establishes the inertial reference plane by measuring the vertical acceleration of the vehicle body. An on board computer processes collected data, storing it on floppy disks. The Road Profiler can also plot the measured profile.

The advantage of this system is its low initial and operating cost. The limitations are that the data reported are slightly less accurate than with the light-based devices, and the data processing system presently used is not compatible with systems used by many other SHAs.

An added advantage to the system is its ability to measure rut depth. By mounting two additional transducers to the front bumper, rut depth (3 points) can be recorded and used to supplement the longitudinal profile (Figure 23). Additional



Rut Depth, D = $(h_1 - 2h_2 + h_3)$

Figure 23 - Rut depth Measurement

transducers could be added if desired to define a full transverse profile.

Several of the most recent devices to appear on the market have used additional transducers to more clearly define the transverse profile. Some use lasers in lieu of the ultrasonic transducers to increase measurement accuracy and frequency, or to measure other pavement parameters such as macrotexture or cracking. A few have supplemented the existing capabilities with additional devices such as gyroscopes in order to provide measurements of most of the pavement features and geometry including roughness, rut depth, grade, cross slope, and radius of curvature.

Lasers

Light Amplification through Stimulated Emission of Radiation (LASER) has fascinated man since Albert Einstein's atomic theories in 1917. Lasers have many applications today; they are used extensively in science, medicine, industry, commerce, communications, the military, and in the laboratory. Their useful purposes are ever growing -- they are used to drill, weld, cut, scribe, unblock arteries, repair eyes, detect drug concentrations in body fluids, transmit and print information, improve the precision of gyroscopes and radar, and track satellites. They also measure very accurately. Their tremendous potential for condition survey measurement is just beginning to be tapped.

Lasers are now manufactured in many types, including chemical lasers, gas lasers, and semiconductor diode lasers. Non-contact laser transducers measure on the principle of triangulation, most often using gallium arsenide diode lasers (Figure 24). The laser

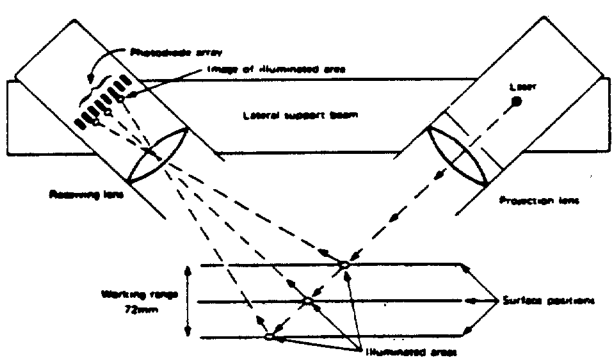


Figure 24 - Laser Measurement Principle

transducer is usually mounted directly to the survey vehicle (Figure 25).

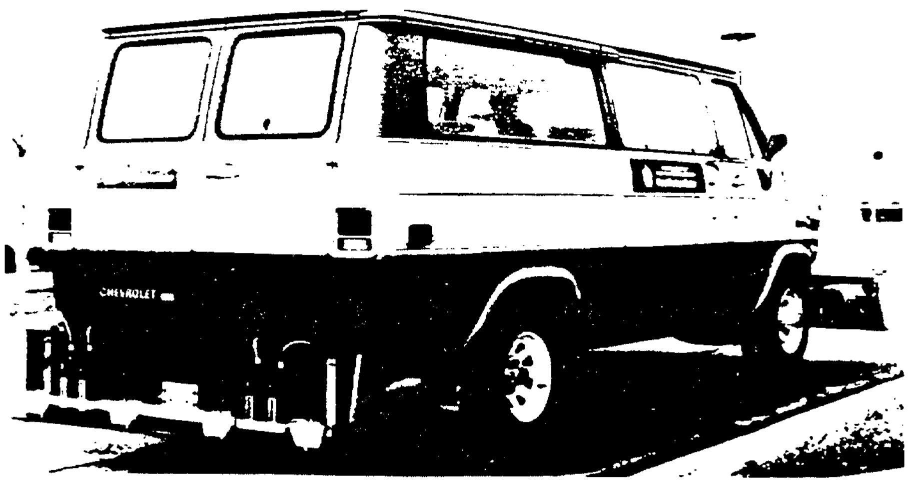


Figure 25 - Lasers installed on a Survey Vehicle

Lasers can operate either during the day or at night at a temperature range from near freezing to about 100 degrees F. During use, the pavement surface should be dry. Lasers possess special properties which allows highly accurate measurement:

- Intensity - the energy is extremely concentrated, as opposed to acoustic transducers, where sound waves are readily diffused
- Monochromatic and Coherent - single-colored light is emitted in a very narrow wave band which is so organized that it stays in phase over long distances
- Collimated - the light is highly directional and travels in a narrow cone
- The energy is generated and reflected back in extremely short pulses which allows a large number of readings to be taken over very short distances even at high speeds

These special properties permit detailed, frequent measurement of the pavement surface characteristics. Lasers are currently used for longitudinal profile, rut depth and macrotexture measurement. A method to measure cracking is under development. Roughness can be measured using the principles described previously. The lasers pulse at either 16,000 hertz (cycles per second) or 32,000 hertz. Even at 60 mph a reading could theoretically be taken each 0.00275 inch, permitting a detailed measurement of the pavement surface texture. In years to come the laser may replace the skid trailers in the search for pavement surfaces with low coefficients of friction. Experimental efforts using lasers for this purpose are underway.

Systems in use today employ the lasers in a variety of numbers, configurations, and locations on the survey vehicle. Similar to the acoustic transducers, 3 to 5 lasers mounted across the vehicle can provide a good transverse profile. Up to 11 lasers have been used for this purpose. Accurate measurements of slab faulting and transverse cracking have been recorded; however, longitudinal cracking is not detectable unless it lies within the small laser footprint. Rapid raster scanning, or closely bunching lasers, could provide a solution to this problem. At least one agency is studying the possibility of detecting all types of cracking by grouping several lasers very closely together, and correlating the measured cracking noted in a small accurately measured area to the entire pavement surface area. Some manufacturers and agencies are also experimenting with lasers for use in continuous deflection devices that will operate at high speeds.

The PRORUT system developed by the University of Michigan for the FHWA provides pavement profile and an average rut depth. The PRORUT is an inertial profilometer which was designed to minimize the overall costs of the system. The vehicle contains three road sensors, one in each wheel track and one centered between the wheel tracks. Two accelerometers are installed in the profilometer, one above the road sensor in each wheel track. The vehicle speed and distance of travel is measured by a pulser installed in the right front wheel. An IBM-PC serves to control the system calibration, operation, data acquisition, and data viewing. Four SHAs have recently evaluated the performance of the PRORUT, and an evaluation report of the findings is being prepared. The device is shown in Figure 26.

Figure 26 - PRORUT

Photographic Evaluation

In the early 1970's two systems were developed that made use of continuous pavement surface photography. These systems are currently in use in Europe, Japan, and recently, in the United States. Cracking and other surface distresses are recorded with a high resolution, continuous pavement surface photographic recorder. The recorder uses a 35-mm slit camera mounted on a boom aimed vertically downward at the pavement surface (Figure 27).

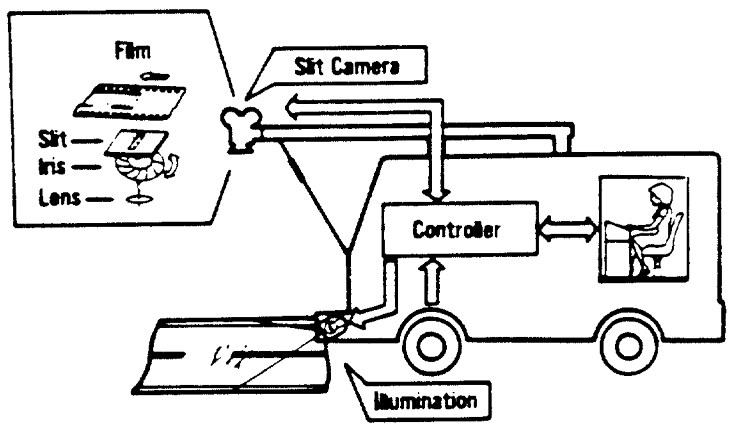


Figure 27 - Schematic of a Continuous Surface Photography Vehicle

The system synchronizes film speed and camera aperture with the speed of the vehicle in order to equalize the image density and photographic reduction. The camera position relative to the pavement is fixed (9.5 feet) resulting in a 1:200 scaled photo reproduction. Pavement widths up to 16 feet can be photographed in each pass. The vehicle operates at night using controlled external illumination. The lights are installed at an angle to the road surface to produce shadows highlighting cracks and other surface defects. The continuous strip photos are saved as a permanent record of the pavement surface condition. In the office, the film is analyzed frame by frame on a film digitizer. Pavement distresses are measured and recorded into a permanent file.

One manufacturer also uses a 35-mm pulse camera and a hairline projector strobe light to photograph rutting wave patterns. The projected hairline parallels the pavement surface, providing an accurate scaled measurement of the rut depth. If no rutting exists and the cross section is uniform, the photographed hairline is straight. In rutted sections the hairline follows the photographed rut pattern permitting very accurate calculation of the rut depth. Both the strobe light and the camera trigger at fixed, adjustable, pre-programmed intervals. The film is then sent for developing, printing, and plotting of the transverse profile.

This system is presently the most fully operational, proven system to measure a wide range of types and severity of pavement distress. The frame by frame analysis, however, is tremendously time consuming, adding significantly to the cost of the system. Efforts to automate the data reduction process are underway.

Video Technology

Nowhere has the effect of the technological explosion of the past 10 years been more apparent than in the area of video technology. Some agencies have turned to videos to provide permanent records of the pavement surface and for other purposes. Features such as identification of signs, utilities, and safety hardware, have been recorded, as have ongoing construction projects, to provide a record of the work and traffic controls during periodic intervals or at key phases of construction.

Videos are replacing the photologging systems in many agencies. In photo-logging, a 35-mm camera is aimed through the windshield of a van, photographing the features in the field of vision 100 times per mile. Video cameras may be installed either to inventory through the windshield, aimed directly down at the pavement surface, or used in both positions.

Video technology offers several advantages over 35-mm photography. Relatively inexpensive, reusable, off-the-shelf technology is readily available. The tape can be replayed in the field where the quality of the record can be immediately verified. Replacement parts and equipment can be easily obtained. The limitation of video is the inferior resolution of the recorded images compared to photographic records. The resolution gap between the two technologies, however, is rapidly narrowing.

The addition of condition rating keyboards and on board computer systems and other instrumentation, allows the condition survey team to supplement the recorded information with distress observations.. Review and supplemental input to the permanent record may be performed in the office, and added to the field-obtained data. Recent systems have added one or more cameras aimed vertically at the pavement surface.

Automated Video Image Processing

Video technology has been in use for about 10 years, and procedures to fully automate the processing and reproduction of the captured images both in real time (immediately after capture on board the vehicle) and in the office environment are now being developed. The automated processing of the recorded analogue images may take several forms.

Conversion to a digital format suitable for image processing is presently the most common. The more limited resolution of video cameras requires use of a very expensive high resolution camera for the detection of small cracks. The high resolution camera, however, is often incompatible with available recorders and digitizing hardware. In order to overcome this shortcoming, either 2 or 3 cameras mounted closer to the pavement surface, each covering an area of about 4'x 4' to 6'x 6' are now in use. This permits detection of small cracks and other surface defects of about 1/8" in size, or smaller. Constant, controlled lighting eliminates the background shadows of passing vehicles and adjacent structures, and minimizes problems related to the changing of the angle of the sun throughout the day.

Digitized processing involves one frame at a time analysis of the recorded analog images. The first step is known as filtering, a process that removes extraneous information that could be misinterpretated as distress. Next, the signal is segmented. Segmentation is based on an intensity threshold and allows the system to identify distinct objects in the scene. Intensities based on the gray scale range from 0 (the whitest white) to 255 (the blackest black). Each analogue image is divided into a matrix of pixels ranging in size from 256 x 256, 512 x 512, or 1024 x 1024, depending on the resolution of the camera. Each pixel in the matrix is assigned a numerical value based on its intensity. A small portion (10 x 10) of a typical matrix is depicted in Figure 28.

In this elementary example, most of the pixels are representative of the normal pavement surface. Processors apply a statistical analysis algorithm to the pixel distribution and establish the range of pixels representing the normal pavement. In this case, values below 107 represented the normal pavement. Values of 107 and above (bold) represent distress, in this case a crack.

99	111	103	98	97	100	103	100	101	102
104	102	110	100	100	104	104	100	102	101
112	**114**	**109**	**114**	99	101	100	96	100	104
107	**112**	**119**	**108**	**111**	**110**	**109**	**111**	**100**	**99**
101	101	98	98	103	104	104	**112**	**115**	**114**
97	96	99	100	101	102	100	100	97	95
101	104	100	97	99	101	102	98	100	100
99	103	103	98	97	100	103	100	101	102
95	97	99	104	103	101	102	100	99	98
104	103	100	97	98	101	102	98	100	100

Figure 28 - A portion of a Pixel Matrix

The resultant reproduced data output may be represented for the covered area in a graphic resembling Figure 29.

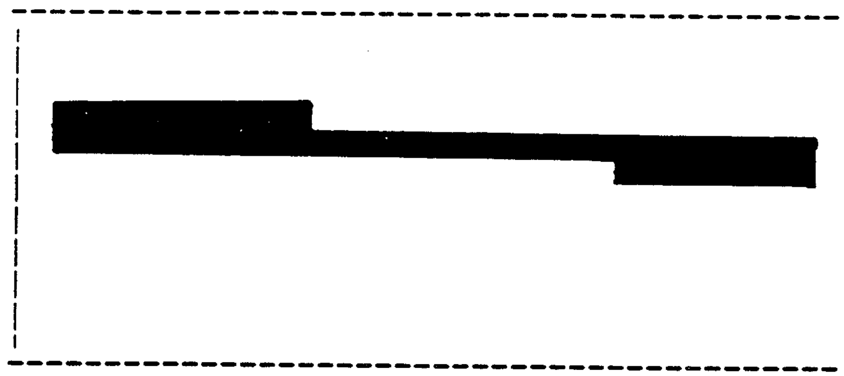


Figure 29 - Reproduction of Pavement Crack through Digitized Processing

The extent and severity can be determined from the matrix and the power of the software. For a 512 x 512 matrix representative of a 4' x 4' pavement section, each pixel would represent an area of pavement measuring 0.09375 square inch, or a little less than 1/10 square inch. Three dark pixels side by side would represent a crack slightly over 1/4 inch wide.

Processors apply software algorithms to identify the edge of the distress, the perimeter and area, and the distress classification. Summary information on distress characteristics is stored and used to create pavement condition summary statistics at intervals specified by the operator. Ultimately, scaled reproductions of the data may be produced on maps; the type, extent, and severity of the distress summarized, and the output used during pavement rehabilitation.

In a 512 x 512 matrix each image contains 262,144 pixels. In standard video formats 30 frames per second are recorded, resulting in the formation of almost 8 million pixels per second. Assuming 3 cameras are used to record a 12 foot wide pavement section, with each camera covering a 4 foot width, about 85 billion pixels would require analysis and processing for each mile of pavement (at 60 mph). Processing obviously requires an extremely high speed microprocessor. Even with today's high speed computers, most data is post processed in the office environment due to the amount of data collected. It is expected that the technology which will be available in a few years to process even this vast amount of information in real time. A summary of these and other distress data collection technologies is contained in Table 3.

TABLE 3 - PAVEMENT DISTRESS DATA COLLECTION TECHNOLOGIES

DATA COLLECTION TECHNOLOGY	DATA REDUCTION TECHNOLOGY	CURRENT USE	DEVELOPMENT TIME IN USE	RELATIVE COST	ADVANTAGES	LIMITATIONS	COMMENTS
Condition Rating Keyboards	Real Time or Office (video)	Growing, Supplements video, network	Operational 10 Years	Low	Low cost Eliminates forms	Subjective Data Entry	Inexpensive, great potential use for small agencies
Acoustic Systems	Real Time or Post Process	Growing, also used for Profile, network	Operational 10 Years	Low to Medium	Low cost for extensive data	Low resolution Affected by weather	Low resolution Affected by weather
Laser Technology	Real Time Analogue & Digital	Growing, also used for Profile & skid, network	Operational 8 Years	Medium to High	Highly accurate & fast, great potential	Expensive	Further development needed for Cracking, skid, & Deflection
Photographic Systems	Post Process Analogue	One Evaluation Completed Research	Operational, 18 yrs 1 Year in USA	High	Permanent Record Good Resolution	Expensive, Manual Processing	Operational system Also for Profile
Video Technology	Post Process Analogue	Growing, Multipurpose	Operational 10 Yrs Being Automated	High	Permanent Record, Many Uses, Great Potential	Expensive, Manual Processing	Uses-Traffic, Safety, potential for rutting & skid
Automated Image Processing	Real Time or Post Process	Evaluations Scheduled Use to date Limited	In Development	Very High	Permanent Record Fully Objective	Technically complex Expensive	May provide extensive coverage and reduce cost, if successful
Seismic & Dynamic Testing	Real Time	Experimental	Experimental	Low	Low Cost	Not yet fully developed	Potential to be Determined
Ground Penetrating Radar	Real Time	Project Level	Experimental Refinements Ongoing	Medium	Detects Problems Not Visible on Surface	Output Reliability depends on experienced technician	Used primarily at the project level
Infrared Thermography	Real Time	Project Level	Experimental Refinements Ongoing	Low to Medium	Detects Problems Not Visible on Surface	Output Reliability depends on experienced technician	Used primarily at the project level
Slit Integration	Real Time or Post Process	None	Formerly Experimental	Medium to High?	Used to develop alternate technologies	Never fully developed Low % crack detection	Never fully developed
Flying Spot Laser Scanners	To be determined	None	In development	To be determined	To be determined	To be determined	In development

OTHER TECHNOLOGIES

Other technologies are also now available and are being used and developed for the purpose of evaluating pavements. These include seismic and dynamic test methods, ground penetrating radar, infrared thermography, slit integration, and flying spot laser scanners. A few of these technologies are now in use, others are being evaluated, developed, or refined. A summary of their respective features is contained in Table 3.

CONCLUSION

Automated processes to collect skid, roughness, and rutting are now available. Automated equipment to measure cracks, and moving deflectometers are still in the research and evaluation stages. Improvements in the ability to collect important pavement data through equipment automation can be expected to continue.
The technological explosion of the 1980's has been a great benefit to Pavement Management Systems. Technologies which were only a theory in the 1960's are now being used on an every day basis. The rate of development of many of the new and innovative technologies is expected to continue into the 1990's and the 21st century. Automated data collection and processing of collected pavement condition data can provide considerable cost savings to user agencies, and improve the mechanisms through which agencies effectively manage their pavements.

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APPENDIX A

LIST OF AUTOMATED PAVEMENT DATA COLLECTION EQUIPMENT MANUFACTURERS & SUPPLIERS*

Cox & Sons, Inc.
P.O. Box 674
Colfax, CA 95713
(916) 346-8322
Cox RTRRM
Friction Tester

Foundation Mechanics Inc.
421 East El Segundo Boulevard
El Segundo, CA 91245
(213) 322-1920
Road Rater

Infrastructure Management Services
3350 Salt Creek Lane
Arlington Heights, IL 60005
Mr. Robert L. Novak
(312) 506-1500
Swedish Laser RST
690DNC Profilometer

Kokusai Kogyo., Ltd.
Abenatak Corporation
1179 Fernwood Drive
Millbrae, CA 94030
Mr. Taizo Abe
Roadman

MAP Inc.
1825 I Street, NW. Suite 400
Washington, D.C. 20006
Mr. Michael Grippon
(202) 429-2089
Gerpho

Pavement Condition Evaluation Services
1145 Icehouse Avenue
Sparks, Nevada 89431
Mr. Bert Butler
(702) 355-0225
Pavement Distress Imager 1

South Dakota DOT
700 Broadway Avenue East
Pierre, SD 57501
Mr. David L. Huft
(605) 773-3871
South Dakota Road Profiler

Dynatest Consulting, Inc.
209 Bald Street
P.O. Box 71
Ojai, California 93203
(805) 646-2230
Dynatest 8000 FWD
Dynatest 5000 RDM

Highway Products International
R.R. #1 Paris, Ontario
Canada N3L 3E1
Mr. Don Kobi
(519) 442-2261
ARAN & PURD

K. J. Law Engineers
42300 W. Nine Mile Rd.
Novi, Michigan 48050-3627
Mr. Ken Law
(313) 347-3300
8300A Roughness Surveyor
Friction Testers

MHM Associates, Inc.
1920 Ridgedale Road
South Bend IN 46614
Mr. Jerry Mohajeri
(219) 291-4793
ARIA

PASCO USA Inc.
1-J Franssetto Way
Lincoln Park, N.J. 07035
Mr. Wade Gramling
(201) 628-8433
Pasco Road Survey System

Pavedex, Inc.
N. 800 Hamilton Ave.
Spokane, Washington 99202
Mr. Don Bender
(509) 483-4126
Pavedex PAS I

VideoComp
500 Sawtooth Ave.
Boise, Idaho 83709
Mr. Basil Dahlstrom
(208) 385-1575
Distress Survey Trailer

* This list has been prepared on the basis of currently available informati in this office. We would appreciate the readers' input if others are known

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U.S. Department of Transportation
Federal Highway Administration

Memorandum

Subject: "Addressing Institutional Barriers to Implementing a PMS" ASTM Paper by Dr. Roger E. Smith

Date: AUG 19 1991

From: Chief, Pavement Division

Reply to Attn of: HNG-41

To: Regional Federal Highway Administrators
Federal Lands Highway Program Administrator

At the recent American Society for Testing Materials Symposium (ASTM) on Pavement Management, the attached stand-out paper, was given by Professor Roger E. Smith, of the Texas Transportation Institute. Dr. Smith has given his permission for us to share his paper with others interested in Pavement Management Systems (PMS).

The paper addresses institutional barriers to implementing PMS (using the San Francisco Bay Area Metropolitan Transportation Commission (MTC) as an example) and is not only an excellent description of these issues, but is also a perfect lead into the September symposium that we are co-sponsoring with the Illinois Department of Transportation (IDOT). You may wish to share it with our divisions and the State highway agencies.

As the States move from development of their PMS's into implementation, success could well hinge on recognition that these barriers exist, and taking steps to overcome them.

Key issues identified in the paper are:

1. If the PMS is not affecting the ultimate decisions on the highway agency's program, then the agency cannot claim to have a PMS implemented.

2. Many PMS's are not being utilized to their fullest potential--often because of surmountable barriers.

3. The most troublesome barriers to implementation of a PMS are people related.

4. Some of the barriers in capsule are:

   - Fear of exposure - Previous decisions may have been incorrect.

   - Turf Protection - There are formal and informal lines of communication within an organization that need to be recognized.

- Black Box Syndrome - The PMS is not fully understood, therefore its products can not be verified.

- One person show - The champion of the PMS leaves and the system dies.

5. Some of the concepts to be considered in surmounting barriers are:

- Innovation - "It is not the actual newness of the innovation but rather the perception of newness to the potential adopter that influences adoption and use."

- Consider the "Opinion Leader" - Know who they are because without their support the system will not be implemented.

- Compatibility - The new system must be compatible with the existing because a complete overhaul or reorganization is usually impossible.

- Trialability - Innovation needs to be adopted in stages. "New ideas that can be tried on a limited basis are more likely to be adopted."

- Observability - This is the degree to which results of innovations are visible to others. If you can show positive results it goes a long way toward selling PMS.

These are of course, only key paraphrasing of the paper and a full understanding of the issues requires a complete reading. We recommend it to all with responsibility for implementation of PMS's.

Louis M. Papet

Attachment

U.S. Department of Transportation

Federal Highway Administration

Order

Subject

PAVEMENT MANAGEMENT COORDINATION

Classification Code	Date
5080.3	April 13, 1992

1. PURPOSE. To provide a forum for coordinating the Federal Highway Administration's (FHWA) Pavement Management Program in the Washington Headquarters, and to provide guidance for coordination in FHWA field offices.

2. CANCELLATION. FHWA Order 5080.2, Pavement Management Coordination, dated March 23, 1987, is canceled.

3. WASHINGTON HEADQUARTERS COORDINATION

a. Pavement issues often involve the activities of several Washington Headquarters offices. To ensure coordination among related offices and activities, a Pavement Management Coordination Group (PMCG) was established in 1980. The membership has been revised from time to time to reflect organizational changes in the Washington Headquarters since establishment of the group.

b. The PMCG consists of the following members:

(1) Chief, Pavement Division, Office of Engineering, will Chair the Group.

(2) Chief, Planning Programs Division, Office of Environment and Planning.

(3) Director, Office of Engineering and Highway Operations Research and Development.

(4) Director, Office of Technology Applications.

(5) Director, Office of Policy Development.

(6) Director, Office of Highway Information Management.

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(7) Director, Office of Motor Carrier Information Management and Analysis.

(8) A Regional Administrator appointed by the Executive Director will serve for 2 years. This assignment will be rotated among the Regional Administrators.

(9) Chief, Pavements Division, Office of Engineering and Highway Operations Research and Development.

(10) Chief, Long Term Pavement Performance Division, Office of Engineering and Highway Operations Research and Development.

(11) Chief, Materials Division, Office of Engineering and Highway Operations Research and Development.

(12) Chief, Engineering Applications Division, Office of Technology Applications.

(13) Chief, Strategic Highway Research Program Implementation Staff, Office of Technology Applications.

c. The PMCG has the following responsibilities:

(1) ensure that pavement related activities [including the need for, the gathering of, and the use of pavement data] by the several Washington Headquarters offices are cooperatively developed and properly coordinated;

(2) identify pavement problems or issues which merit attention by the FHWA;

(3) participate in field reviews as requested or needed;

(4) serve as the Research, Development, and Technology Coordinating Group for the pavement area as required by FHWA Order 6000.2, Research, Development, and Technology Advisory Councils;

(5) support the FHWA involvement in the Strategic Highway Research Program (SHRP) and the implementation of the products resulting from SHRP, and coordinate the activities of the various programs, studies, and groups involved in the Long Term Pavement Performance evaluation; and

(6) recommend FHWA policies, programs, or actions to improve effectiveness of pavement-related activities of FHWA, State highway agencies (SHA), and local governments.

d. A Technical Working Group (TWG) will assist the PMCG in developing and monitoring pavement-related activities. Each Office Director in the PMCG will appoint at least one representative to serve on the TWG.

(1) The Chief, Pavements Division, Office of Engineering and Highway Operations Research and Development will chair the TWG.

(2) The chairperson may create working groups for specific technical areas as they deem necessary. Each working group will elect its own chairperson, who shall be a member of the TWG.

4. FIELD COORDINATION

a. To provide necessary emphasis to pavement management activities, and to provide the support required to implement FHWA policies and programs in the pavement area, FHWA field offices should develop coordinating mechanisms and assign specific responsibilities for pavement activities.

b. Each regional office should:

(1) assure coordination of pavement-related activities within the region, including but not limited to research, technology transfer, Highway Performance Monitoring System (HPMS), SHRP, annual conferences, and vehicle weight enforcement program;

(2) develop regional operations plans to assist division offices in aiding States and local governments in the conduct of coordinated pavement management programs;

(3) monitor and evaluate pavement-related activities within the region and provide recommendations to improve their effectiveness;

(4) designate a pavement management coordinator to serve as the focal point for all pavement-related activities in the region; and

(5) promote the full range of resources available to strengthen the technical capabilities of local government, SHA, and FHWA personnel in pavement-related areas. Resources available include annual conferences, training courses, and other technology transfer activities and materials, as well as technical expertise within the FHWA staff.

c. Each division office is expected to:

(1) designate a pavement management coordinator to ensure that pavement-related activities, including new and rehabilitated pavement design and construction, pavement management, research, technology transfer, HPMS, vehicle weight enforcement program, etc., are well coordinated among functional/administrative areas of the division office;

(2) monitor and evaluate pavement activities and programs, determine short and long-term needs, and formulate operations plans for meeting these needs; and

(3) take full advantage of available resources to strengthen the technical capabilities of local government, SHA, and FHWA personnel in pavement-related areas. Resources available include annual conferences, training courses, other technology transfer activities and materials, as well as technical expertise within the FHWA staff.

T. D. Larson
Federal Highway Administrator

The NHS Designation Act of 1995, Section 205(a) - Suspension of Management Systems, made PMS a State option and no longer required by federal law. The interim management systems regulation is being revaluated.

SUBCHAPTER F—TRANSPORTATION INFRASTRUCTURE MANAGEMENT

PART 500—MANAGEMENT AND MONITORING SYSTEMS

Authority: 23 U.S.C. 134, 135, 303 and 315; 49 U.S.C. app. 1607; 23 CFR 1.32; and 49 CFR 1.48 and 1.51.

Subpart A—General

§ 500.101 Purpose.

The purpose of this part is to implement the requirements of 23 U.S.C. 303, Management Systems, which requires State development, establishment, and implementation of systems for managing highway pavement of Federal-aid highways (PMS), bridges on and off Federal-aid highways (BMS), highway safety (SMS), traffic congestion (CMS), public transportation facilities and equipment (PTMS), and intermodal transportation facilities and systems (IMS). Section 303 also requires State development, establishment, and implementation of a traffic monitoring system for highways and public transportation facilities and equipment. This subpart includes definitions and general requirements that are applicable to all of these systems. Additional requirements applicable to a specific system are included in subparts B through H of this part.

§ 500.103 Definitions.

Unless otherwise specified in this part, the definitions in 23 U.S.C. 101(a) are applicable to this part. As used in this part:

Certifying official(s) means the position(s) designated by the Governor of a State or the Commonwealth of Puerto Rico or the Mayor of the District of Columbia to certify that the management system(s) is/are being implemented in the State.

Cooperation means working together to achieve a common goal or objective.

Federal agency(ies) means for the PMS and BMS, the Federal Highway Administration (FHWA); for the SMS, the FHWA and the National Highway Traffic Safety Administration; for the CMS, PTMS, and IMS, the FHWA and the Federal Transit Administration (FTA).

Federal-aid highways means those highways eligible for assistance under title 23, U.S.C., except those functionally classified as local or rural minor collectors.

Highway Performance Monitoring System (HPMS) means the State/Federal system used by the FHWA to provide information on the extent and physical condition of the nation's highway system, its use, performance, and needs. The system includes an inventory of the nation's highways including traffic volumes.

Life-cycle cost analysis means a procedure for evaluating the economic worth of one or more projects or investments by discounting future costs over the life of the project or investment.

Management system means a systematic process, designed to assist decisionmakers in selecting cost-effective strategies/actions to improve the efficiency and safety of, and protect the investment in, the nation's transportation infrastructure. A management system includes: Identification of performance measures; data collection and analysis; determination of needs; evaluation and selection of appropriate strategies/actions to address the needs; and evaluation of the effectiveness of the implemented strategies/actions.

Metropolitan planning area means the geographic area in which the metropolitan transportation planning process required by 23 U.S.C. 134 and section 8 of the Federal Transit Act (49 U.S.C. app. 1607) must be carried out.

Metropolitan planning organization (MPO) means the forum for cooperative transportation decisionmaking for a metropolitan planning area.

National highway system (NHS) means the system of highways designated and approved in accordance with the provisions of 23 U.S.C. 103(b).

Performance measures means operational characteristic, physical condition, or other appropriate parameters used as a benchmark to evaluate the adequacy of transportation facilities and estimate needed improvements.

State means any one of the fifty States, the District of Columbia, or Puerto Rico.

Transportation Management Area (TMA) means an urbanized area with a population over 200,000 (as determined by the latest decennial census) or other area when TMA designation is requested by the Governor and the MPO (or affected local officials), and officially designated by the Administrators of the FHWA and the FTA. The TMA designation applies to the entire metropolitan planning area(s).

Work plan means a written description of major activities necessary to develop, establish, and implement a management or monitoring system, including identification of responsibilities, resources, and target dates for completion of the major activities.

§ 500.105 Development, establishment, and implementation of the systems.

(a) Each State shall develop, establish, and implement the systems identified in § 500.101. Each State shall tailor the systems to meet State, regional, or local goals, policies, and resources, but the systems must meet the requirements as specified in subparts B through H of this part. Documentation that describes each management system shall be maintained by the States for the Federal agencies to determine, on a periodic basis, whether the systems meet the requirements in this subpart and subparts B through H of this part, as applicable.

(b) Each State shall have procedures, within the State's organization, for coordination of the development, establishment, implementation and operation of the management systems. The procedures must include:

(1) An oversight process to assure that adequate resources are available for implementation and that target dates in the work plan(s) are met;

(2) The use of data bases with a common or coordinated reference systems and methods for data sharing; and

(3) A mechanism to address issues related to the purposes of more than one management system.

(c) In developing and implementing each management system, the State shall cooperate with MPOs in metropolitan areas, local officials in non-metropolitan areas, affected agencies receiving assistance under the Federal Transit Act and other agencies (including private owners and operators) that have responsibility for operation of the affected transportation systems or facilities.

(d) In accordance with the provisions of 23 U.S.C. 134(l)(3) and 49 U.S.C. app. 1607(l)(3) and the requirements of 23 CFR part 450, the CMS shall be part of the metropolitan planning process in TMAs.

(e) Within metropolitan planning areas, the CMS, PTMS, and IMS shall, to the extent appropriate, be part of the metropolitan transportation planning process required under the provisions of 23 U.S.C. 134 and 49 U.S.C. app. 1607.

(f) In metropolitan planning areas that have more than one MPO and/or that include more than one State, the establishment, development, and implementation of the CMS, PTMS, and IMS shall be coordinated among the State(s) and MPO(s) to ensure compatibility of the systems and their results.

(g) The results (e.g., policies, programs, projects, etc.) of the individual management systems shall be considered in the development of metropolitan and statewide transportation plans and improvement programs and in making project selection decisions under title 23, U.S.C., and under the Federal Transit Act.

(h) The roles and responsibilities of the State, MPO(s), recipients of assistance under the Federal Transit Act, and other agencies involved in the development, establishment, and implementation of each system shall be mutually determined by the parties involved. A State may enter into agreements with local governments, regional agencies (such as MPOs), recipients of funds under the Federal Transit Act, or other entities to develop, establish, and implement appropriate parts of any or all of the systems, but the State shall be responsible for overseeing and coordinating such activities.

(i) Section 204(a) of title 23, U.S.C., requires the Secretary in cooperation with the Secretaries of the Interior and Agriculture to develop the safety, bridge and pavement management systems for Federal lands highways, as defined in 23 U.S.C. 101(a). To avoid duplication of effort, the management systems required under this part should be used to the extent appropriate to fulfill the requirement in 23 U.S.C. 204(a) regarding establishment and implementation of pavement, bridge, and safety management systems for Federal lands highways. The State, the Federal agencies, and the agencies that own the roads shall cooperatively determine responsibility for coverage of Federal lands highways under their respective jurisdictional control and shall ensure that the results of the PMS, BMS, and SMS for Federal lands highways are available, as appropriate, for consideration in developing metropolitan and statewide transportation plans and improvement programs and are provided to the FHWA for use in developing Federal lands highway programs.

(j) Each management system must include appropriate means to evaluate the effectiveness of implemented actions developed through use of that system. The effectiveness of the management systems in enhancing transportation investment decisions and improving the overall efficiency of the State's transportation systems and facilities shall be evaluated periodically, preferably as part of the metropolitan and statewide planning processes.

§ 500.107 Compliance.

(a) States must be implementing the management systems specified in subparts B through G of this part beginning in Federal fiscal year 1995 (October 1, 1994 to September 30, 1995) and must certify annually to the Secretary of Transportation that they are implementing each of the management systems. A State shall be considered to be implementing a management system if the system is under development or in use in accordance with the compliance schedule for that system as specified in subparts B through G of this part.

(b) The Governor of the State or the Commonwealth of Puerto Rico or the Mayor of the District of Columbia shall notify the FHWA Division Administrator in writing by September 30, 1994, of the title(s) of the certifying official(s) for each management system. If there is a change in designated position(s), the State shall provide documentation of the revised designation with, or prior to, the next annual certification. In those States where responsibility for all of the management systems is within a single agency (e.g., State DOT), designation of one certifying official for all of the management systems is recommended.

(c) The certification statement(s) shall be submitted by the certifying official(s) to the FHWA Division Administrator by January 1 of each year, beginning January 1, 1995. To the extent possible, one certification statement should cover all six management systems. If more than one certification statement will be submitted by a State, the statements should be coordinated at the State level and submitted simultaneously. The first certification statement shall include a copy of the workplan(s), required in accordance with the compliance schedule for each management system, and a summary of the status of implementation of the management system(s). Subsequent certification statement(s) shall include a summary of the status of implementation of each management system and a discussion of planned corrective actions for any management system(s) or subsystem(s) that are not under development or fully operational in accordance with the compliance schedule and work plan for the management system.

(d) The FHWA Division Administrator will provide copies of the certification statement(s) and any relevant supporting documentation and correspondence to other Federal agencies identified for the specific system(s) in § 500.103. Within 90 days of receipt, the Federal agencies will review the certification and the FHWA Division Administrator will notify the State whether the certification is acceptable or if sanctions may be imposed in accordance with the provisions of § 500.109.

(e) A State shall be considered to be implementing the traffic monitoring system for highways (TMS/H), specified in subpart H of this part, if the system is under development or in use in accordance with the compliance schedule in § 500.809. The State shall submit the work plan for the TMS/H to the FHWA Division Administrator by January 1, 1995.

(The information collection requirements in paragraphs (c) and (e) of § 500.107 have been approved by the Office of Management and Budget under control number 2125–0555.)

§ 500.109 Sanctions.

(a) Beginning January 1, 1995, if a State fails to certify annually as required by this regulation, or if the Federal agencies determine that any management system or subsystem, specified in subparts B through G of this part, is not being adequately implemented, notwithstanding the State's certification(s), the Secretary may withhold up to 10 percent of the funds apportioned to the State under title 23, U.S.C., and to any recipient of assistance under the Federal Transit Act for any fiscal year beginning after September 30, 1995. Sanctions may be imposed on a statewide basis, on a subarea of a State, for specific categories of funds or types of projects, or for specific recipients or subrecipients of funds under title 23, U.S.C., or under the Federal Transit Act depending on the adequacy of implementation of the management systems.

(b) While a State may enter into agreements with local governments or other agencies to develop, establish, and implement all or parts of the management systems, in accordance with § 500.105(g), the State shall be responsible for ensuring that the systems are being implemented statewide and for taking any necessary corrective action, including implementing the systems at the regional and local levels if necessary.

(c) Prior to imposing a sanction, a State will be notified in writing by the FHWA of the sanction(s) to be imposed, the reasons for the sanctions, and the actions necessary to correct the deficiencies. After 60 days from the date of notification to the State, the Federal agencies will consider any corrective actions proposed by the State and the FHWA will notify the State if such actions are acceptable or if sanctions are to be applied.

(d) In instances where a State, or responsible sub-unit of a State or recipient of funds under the Federal Transit Act, has not fully implemented all of the management systems, consideration shall be given by the Federal agencies to efforts underway or planned to make the systems fully operational within a reasonable time period.

(e) To the extent that they have not lapsed, funds withheld pursuant to this subpart shall be made available to the State or recipient under the Federal Transit Act upon a determination by the Federal agencies that the management systems are being adequately implemented.

§ 500.111 Funds for development, establishment, and implementation of the systems.

(a) The following categories of funds may be used for development, establishment, and implementation of any of the management and monitoring systems: National Highway System, Surface Transportation Program, FHWA State planning and research and metropolitan planning funds (including the optional use of minimum allocation funds authorized under 23 U.S.C. 157(c) for carrying out the provisions of 23 U.S.C. 307(c)(1) and 23 U.S.C. 134(a)), Federal Transit Act Section 8 (49 U.S.C. app. 1607), Federal Transit Act Section 9 (49 U.S.C. app. 1607a), Federal Transit Act Section 26(a)(2) (49 U.S.C. app. 1622(a)(2)), and Federal Transit Act Section 26(b)(1) (49 U.S.C. app. 1626(b)(1)). Congestion Mitigation and Air Quality Improvement Program funds (23 U.S.C. 104(b)(2)) may be used for those management systems that can be shown to contribute to the attainment of a national ambient air quality standard. Apportioned bridge funds (23 U.S.C. 144(e)) may be used for development and establishment of the bridge management system.

(b) Federal funds identified in paragraph (a) of this section used for development, establishment, or implementation of the management and monitoring systems shall be administered in accordance with the procedures and requirements applicable to the category of funds.

§ 500.113 Acceptance of existing management systems.

(a) Existing State laws, rules, or procedures that the Federal agencies determine fulfill the purposes of a management system, or portion thereof, as specified in this part may be accepted by the Federal agencies in lieu of development and implementation of a new system.

(b) If a State has existing laws, rules, or procedures that it wants to use to meet the requirements of this part, it shall submit a written request to the FHWA Division Administrator that the Federal agencies accept the existing management system in lieu of development of a new system. The request shall include a discussion, and any necessary supporting documentation, that shows how the existing system meets the requirements of this part. The documentation shall reflect the views of the MPOs, transit operators, and other affected agencies, as appropriate, and the actions to be taken to assure that the cooperation required under § 500.105(c) is established.

(c) Upon receipt of a request, the FHWA Division Administrator will coordinate review of the request with the other Federal agencies specified in § 500.103 and with appropriate FHWA offices. Within 90 days of receipt of the State's request, the FHWA will notify the State that the existing system is either fully acceptable, acceptable subject to specific modifications, or unacceptable and that a new system must be developed.

(d) To meet the compliance schedule for a system, the State must submit any requests under paragraph (a) of this section no later than June 1, 1994.

Subpart B—Pavement Management System

§ 500.201 Purpose.

The purpose of this subpart is to set forth requirements for development, establishment, implementation, and continued operation of a pavement management system (PMS) for Federal-aid highways in each State in accordance with the provisions of 23 U.S.C. 303 and subpart A of this part.

§ 500.203 PMS definitions.

Unless otherwise specified in this part, the definitions in 23 U.S.C. 101(a) and § 500.103 are applicable to this subpart. As used in this part:

Pavement design means a project level activity where detailed engineering and economic considerations are given to alternative combinations of subbase, base, and surface materials which will provide adequate load carrying capacity. Factors which are considered include: materials, traffic, climate, maintenance, drainage, and life-cycle costs.

Pavement management system (PMS) means a systematic process that provides, analyzes, and summarizes pavement information for use in selecting and implementing cost-effective pavement construction, rehabilitation, and maintenance programs.

§ 500.205 PMS general requirements.

(a) Each State shall have a PMS for Federal-aid highways that meets the requirements of § 500.207 of this subpart.

(b) The State is responsible for assuring that all Federal-aid highways in the State, except those that are federally owned, are covered by a PMS. Coverage of federally owned public roads shall be determined cooperatively by the State, the FHWA, and the agencies that own the roads.

(c) PMSs should be based on the concepts described in the "AASHTO Guidelines for Pavement Management Systems."[1]

(d) Pavements shall be designed to accommodate current and predicted traffic needs in a safe, durable, and cost-effective manner.

§ 500.207 PMS components.

(a) The PMS for the National Highway System (NHS) shall, as a minimum, consist of the following components:

(1) Data collection and management.

(i) An inventory of physical pavement features including the number of lanes, length, width, surface type, functional classification, and shoulder information.

(ii) A history of project dates and types of construction, reconstruction, rehabilitation, and preventive maintenance.

(iii) Condition surveys that include ride, distress, rutting, and surface friction.

(iv) Traffic information including volumes, classification, and load data.

(v) A data base that links all data files related to the PMS. The data base shall be the source of pavement related information reported to the FHWA for the HPMS in accordance with the HPMS Field Manual.[2]

(2) Analyses, at a frequency established by the State consistent with its PMS objectives.

(i) A pavement condition analysis that includes ride, distress, rutting, and surface friction.

(ii) A pavement performance analysis that includes an estimate of present and predicted performance of specific pavement types and an estimate of the remaining service life of all pavements on the network.

(iii) An investment analysis that includes:

(A) A network-level analysis that estimates total costs for present and projected conditions across the network.

(B) A project level analysis that determines investment strategies including a prioritized list of recommended candidate projects with recommended preservation treatments that span single-year and multi-year periods using life-cycle cost analysis.

(C) Appropriate horizons, as determined by the State, for these investment analyses.

(iv) For appropriate sections, an engineering analysis that includes the evaluation of design, construction, rehabilitation, materials, mix designs, and preventive maintenance as they relate to the performance of pavements.

(3) Update. The PMS shall be evaluated annually, based on the agency's current policies, engineering criteria, practices, and experience, and updated as necessary.

(b) The PMS for Federal-aid highways that are not on the NHS shall be modeled on the components described in paragraph (a) of this section, but may be tailored to meet State and local needs. These components shall incorporate the use of the international roughness index or the pavement serviceability rating data as specified in Chapter IV of the HPMS Field Manual.

§ 500.209 PMS compliance schedule.

(a) By October 1, 1994, the State shall develop a work plan that identifies major activities and responsibilities and includes a schedule that demonstrates full operation and use of the PMS on the NHS by October 1, 1995, and on non-NHS Federal-aid highways by October 1, 1997.

(b) By October 1, 1995:

(1) The PMS for the NHS shall be fully operational and shall provide projects and programs for consideration in developing metropolitan and statewide transportation plans and improvement programs; and

(2) PMS design for non-NHS Federal-aid highways shall be completed or underway in accordance with the State's work plan.

(c) By October 1, 1997, the PMS for non-NHS Federal-aid highways shall be fully operational and shall provide projects and programs for consideration in developing metropolitan and statewide transportation plans and improvement programs.

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[1] AASHTO Guidelines for Pavement Management Systems, July 1990, can be purchased from the American Association of State Highway and Transportation Officials, 444 N. Capitol Street, NW., suite 225, Washington, DC 20001. Available for inspection as prescribed in 49 CFR part 7, appendix D.

[2] Highway Performance Monitoring System (HPMS) Field Manual for the Continuing Analytical and Statistical Data Base, DOT/FHWA, August 30, 1983, (FHWA Order M5600.1B). Available for inspection and copying as prescribed in 49 CFR part 7, appendix D.