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# Pavement Condition Evaluation

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## *Foreword*

Since its reorganization in 1961, the Highway Research Board Committee on Pavement Condition Evaluation has been actively engaged in the study of methods for making condition surveys in the field and evaluating the results in terms of pavement serviceability and performance. During 1962, discussion at the several meetings indicates that ideas have been crystallizing on several phases of pavement condition evaluation. The Committee felt that the time was ripe to give its activities wider dissemination and to solicit discussion and comment from highway engineers actively engaged in other phases of pavement design and performance.

With this in mind, the Committee proposed to hold an open forum or conference session at the 42nd Annual Meeting of the Highway Research Board in the hope that such a forum would help to define the important concepts concerning pavement evaluation and establish guidelines for continued work. This meeting was then planned without formal papers in order to stimulate more widespread discussion. However, it was realized that the success of such a meeting would depend on advance preparation and planning. A group of leading discussers was selected to present the more important topics, as indicated in the following outline:

Need for Making Condition Surveys:
- Highways—W.N. Carey, Jr., Highway Research Board
- Airports—Phillip L. Melville, Office, Chief of Engineers

What Characteristics Should Be Measured to Determine Pavement Condition:
- Flexible Pavements—Alfred W. Maner, The Asphalt Institute
- Rigid Pavements—W.E. Teske, Portland Cement Association

Analysis and Use of Condition Data:
- Design of Pavements--Frank P. Nichols, Jr., Virginia Council of Highway Investigation and Research
- Maintenance--A. B. Moe, Bureau of Yards and Docks
- Effect of Condition on Vehicle—B.E. Quinn, Purdue University
- Serviceability Ratings of Highway Pavements--Harold L. Michael, Joint Highway Research Project, Purdue University
- Planning and Road Life—Gordon D. Gronberg, Bureau of Public Roads

Summary—W.S. Housel, University of Michigan

Open Discussion from the Floor

Following the meeting, the Committee felt that the interest generated and the reception that this presentation received justified publication of the prepared discussions and that part of the open discussion supported by written material.

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# The Need for Making Condition Surveys of Highways

W. N. CAREY, JR., Deputy Executive Director, Highway Research Board

The most important need for condition surveys of highways is to establish trends of pavement condition with time in order that advance estimates of maintenance needs and costs can be made. Condition surveys are also needed to provide information on the performance of particular materials and construction techniques. A further need is to provide information on the performance of particular contractors and the quality of construction inspection.

•THE question of "need" for condition surveys is recognized and the author believes this question should be asked more than casually about all efforts, particularly in research. Too often the need for an endeavor is assumed on very scanty and very subjective evidence.

The need is subtly tied to the extent of the effort. When it is agreed that certain information is needed, a small effort may be justified but not a large one. On the other hand, a large one may be required where a small effort would be wasted.

It is very easy, although sometimes expensive, to accumulate masses of data. One attitude permits such accumulation on the assumption that it may be of use later. The modern scientific attitude is quite different. It is more efficient in terms of time and money in the overall endeavor to expend more effort in planning and less in "shotgun" data gathering. A good rule is to forego the self-satisfying extravagance of collecting information on everything that intuitively might prove to be useful and to insist that every number written down or every observation recorded is to be used in a prespecified way in the particular endeavor contemplated. How can the materials needed for a structure be determined without a complete set of plans for using the materials? In experimental research, objectives should be converted to specific plans before it is decided what data are really needed.

This has been a diversion, but it is a most important point.

Condition surveys cost time and money. What return can be expected from this expenditure? In this short discussion I hope to point to several reasons why there is indeed a need for condition surveys. In fact, my main point will be that such a need is more apparent today than ever before.

For this discussion the broad concept developed at the AASHO Road Test for pavement performance is used; not necessarily the specifics—just the concept that pavements are intended to serve the public and that their ability to serve deteriorates with time and traffic. The ability to serve is called "condition" here rather than serviceability. Furthermore, the trend of condition with time and associated loading is pavement performance or behavior.

Now, the important fact is that the Road Test established some definite relationships among performance, design, and load applications. The NCHRP studies devoted to extending the Road Test findings to other conditions are intended to provide the missing information concerning time, environment, and materials. Thus, it will soon be possible to predict with some certainty the condition of a pavement at any point in the future if its condition history up to now and its design, environment, previous load history and future loading expectations are known.

Condition surveys need to be made in order to have in hand the condition history for future condition prediction. This prediction is necessary to meet the most important needs of highway engineers and administrators in the next few years. This is the prediction of future maintenance costs.

There is an awareness of the adverse publicity that, however unjust, has been made in the recent past. In spite of all the ridiculous claims of corruption and inefficiency, highway engineers have completed with some fanfare a large portion of the interstate and a good many other new highways as well. Now, it has been suggested by those who are looking ahead that these new facilities, because they attract such heavy traffic, will not last the 15 to 25 years conventionally assumed by the public and, unfortunately, by most highway engineers. In some cases serious trouble has already been experienced with recently completed highways.

If there is a chance of the need for heavy maintenance on major new highways in five to eight years instead of 15 to 20 years, it appears that the public hue and cry may be terrific.

Criticism can and should be forestalled by an early recognition of the possible need for heavy maintenance. Such recognition should be coupled with well-laid plans for the handling of traffic during maintenance, with public information programs conceived well in advance of the fact, and, most important, with fiscal planning to provide the needed funds for heavy maintenance in advance of their need so as to avoid the bad publicity bound to result from any emergency financing program. Such action would not only forestall bad publicity, but also is simply a matter of good management applicable to any organization that is providing a service.

For the first time, engineers have available scientific tools for predicting future maintenance needs. These tools require rather well-defined condition histories for all highways under consideration. To maintain such histories, condition surveys and evaluations based on objective measurements should be made.

Pavement condition surveys are needed for other reasons perhaps as important in the long run but less urgent. Condition histories made up of information coming from periodic condition surveys when coupled with traffic histories provide the only objective means for evaluation of various new materials and pavement structure designs. Trends in carefully maintained condition histories may serve to indicate, at an early date, potential undesirable performance of pavements of certain designs or pavements containing certain materials. Early detection of such bad performers will permit the highway department to change its specifications and forestall large-scale trouble long before the faulty pavement has actually shown its true colors to the average highway user.

The final proving ground for any innovation in structure design or in the selection or treatment of materials is the highway in actual service. Design and materials engineers need more than a casual impression as to how their innovations are working out. This applies, in fact, not only to innovations but to pavements that have been considered tried and true, because many of these have never before been subjected to the traffic they are now experiencing or will in the future. Only through objective condition surveys can engineers develop sufficient information on which to base sound decisions in such matters.

Still another need for condition surveys is to provide highway administrators with information on the relative effectiveness of their various construction inspection teams and on the various contractors who are building their highways. It may be assumed that the trend towards quality control of construction materials and processes will be accelerated and that ultimately means will be found to insure that the materials used and the structural components of a pavement will be as-specified within reason. Additional effort is warranted, however, to insure that the final product will satisfactorily serve the traveling public. Here perhaps the emphasis is primarily on smoothness of the surface. The conventional tools of condition surveys are highly adaptable as means for determining the satisfactoriness of the final pavement product from the point of view of the user. It has been suggested and it may well be a good idea that construction specifications should include specific limits for final pavement smoothness, to be measured by one or more of the better available instruments. Thus there appears to be a need for condition surveys, or at least parts of condition surveys, at the time a contractor is preparing to turn his pavement over to the state.

The most important and perhaps the most obvious needs for making condition surveys of highway pavements have been briefly discussed. Summarizing, condition surveys are needed for: (a) the administrator and the maintenance engineer in planning for future maintenance needs; (b) the design and materials engineers in order that they may learn the results of innovations in structural design or the use of new materials; and (c) the construction engineer and the administrator to furnish objective criteria that can be used to evaluate the manufactured product.

# Need for Making Airfield Condition-Evaluation Surveys

PHILLIP L. MELVILLE, Civil Engineering Branch, Engineering Division, Military Construction, Office of the Chief of Engineers

•SYSTEMATIC surveys are needed for military and civil airfield pavements to obtain information on their functional value and their service behavior. Thus the need is twofold: first, to establish the suitability of a pavement to perform its function of carrying loads without distress, and second, to analyze the condition of a pavement from its surface appearance and smoothness. Both parts are important because they test the validity of the design procedure.

In other words, it is from the ability of a pavement to perform as anticipated or currently desired that the airport engineer will place a value which will reflect not only the condition of the surface, subjectively or objectively noted, but also what traffic it can carry efficiently, economically and safely.

Condition and evaluation surveys are interrelated. An evaluation report is made from the analysis of each layer of a pavement structure. It is needed to furnish information on the magnitude and frequency of loading that can be permitted without distressing the pavement. For example, at a given military field, how many cycles of operation can be applied to a given item of pavement by a KC 135 jet tanker weighing about 300, 000 pounds without causing distress or requiring excessive maintenance? If no cycle can be applied, what reduction in load is necessary to keep the item usable? Can the aircraft be serviced on a given parking apron? At a civil airport what will be the effect on pavement life from a change by airlines to a heavier airplane and/or to more frequent service? Evaluation surveys are therefore primarily pointed at determining the strength of the materials.

A condition report also provides information on the strength of materials but it is primarily pointed toward appearance, smoothness, and incipient and localized defects or failures. The information is needed because it affects both the traffic from the point of view of safety and convenience and the pavement from the point of view of appropriate "housekeeping."

In fact, the report correlates the following factors:

1. Traffic volume.
2. Tire pressure.
3. Wheel distribution.
4. Weights and overloads.
5. Jet blast.
6. Fuel spillage.
7. Maintenance.
8. Safety.
9. Physical properties of each pavement layer.
10. Climatic factors.

The information is used by the design engineer to make improvements in:

1. Design method (geometric and structural).
2. Construction control.
3. Materials testing.
4. Maintenance methods.

A special case for condition surveys is the failure survey which is needed when a pavement cannot safely carry traffic. At such a time the cause of the failure, remedial action, and necessary steps to prevent recurrence of the same or similar failures are determined from a series of tests. The several variables measured are compared with those used at the time of design and construction to determine if the pavement has performed as it should. Another kind of condition survey is in the detailed follow-up on an experimental section or a section subjected to special traffic.

The engineer needs to know the physical state and strength of a pavement for a check of his design and to be able to furnish guidance to using agencies on how to use available facilities. The using agencies include the airlines, airport managers, pilots, and their military counterparts.

The information obtained from evaluations and condition surveys includes normal operations, emergency condition, and special conditions such as those resulting from frost. The evaluation is given as a set of numbers which include allowable load, tire pressure, configuration of the loading gear, and allowable number of load applications before failure is anticipated. These numbers are obtained by working the design method in reverse and not by "measuring" past or future maintenance. This requires testing each of the existing pavement layers for thickness, strength and compaction as input and deriving the load-carrying ability.

It will be noted that such factors as riding quality and safety factors, which are so often brought forward as items the highway engineer must give great weight to in his survey, are also of concern to the airfield paving engineers especially where jet airplanes are used. But it may be that with the much greater weights of airplanes than of highway vehicles, the major significance of the airfield pavement surface can only be considered in relation to the entire pavement structure. This results in a greater need for the airfield engineer to evaluate the surface solely as a part of the entire structure.

# Measurements for Determining Flexible Pavement Condition

ALFRED W. MANER, Staff Engineer, The Asphalt Institute, College Park, Maryland

•BEFORE selecting the measurements to make for finding a flexible pavement's condition, the purpose of the survey must be decided; then, how the pavement is used must be considered.

Usually, there are two reasons for making condition surveys: to determine ridability, how well the pavement rides; or to determine structural adequacy, the ability of the pavement structure to carry without failure the traffic using it.

Ridability is a measure of the surface condition of the pavement and it depends on superficial defects that affect the riding quality. The fact that these surface defects may reflect some internal failure in the pavement structure is not considered in the evaluation.

A pavement condition survey method, based on ridability, was developed at the AASHO Road Test. The method, called "present serviceability," is defined by Carey and Irick in HRB Bulletin 250 as "the ability of a specific section of pavement to serve high-speed, high-volume mixed ... traffic in its existing condition."

Present serviceability is expressed as an index number derived by giving, in a present serviceability index (PSI) equation, various weights to the following measurements: (a) roughness, (b) rut depth, (c) major cracking, and (d) patching.

The PSI, as defined, will not suit the criteria for city streets, secondary roads, or airports without adjustment of the level of acceptability or, possibly, adjustment of the coefficients in the PSI equation to fit the new criteria. This is why pavement usage must be considered as an influence in the condition survey.

Roughness measurements, into which are lumped all types of surface disintegration and distortion, are the biggest influence in the present serviceability concept. Although rut depth, major cracking, and patching are measured, they are given but little weight in the PSI equation.

Present serviceability may tell the engineer that the surface is rough and resurfacing is needed, but it does not tell him whether or not structural repairs are required or why the pavement is performing as it is. For this he must determine the structural adequacy of the pavement. He does it with a structural condition survey.

Structural condition is the ability of a pavement structure, at the time of the condition survey, to carry the traffic using it. Necessarily, then, more detailed measurements of all defects are needed for evaluation than for the present serviceability index. Each defect must be isolated and classified and a knowledge of the causes of the different defects must be used to determine what repairs are needed to make the structure adequate again. This kind of information also is needed to evaluate pavement design, so, in this type of condition survey, cracking, disintegration, and distortion are measured, and they show up in a number of varieties. The following shows varieties of defects and their probable causes:

Cracking.—(a) alligator or map, plastic or resilient foundation; (b) shrinkage, drying out and shrinkage of mix or underlying layers; (c) slippage, lack of bond between the surface and the next layer because of fine dust or moisture, or both; (d) longitudinal, downward and lateral movement of fill or poor construction joint; and (e) transverse, contraction due to temperature or overstress of pavement.

Disintegration.—(a) raveling, insufficient bitumen or action of water; and (b) potholes, insufficient bitumen, plastic fines, or action of water.

Distortion.—(a) corrugations, unstable mix or unstable base; (b) pushing or shoving, unstable mix (too much bitumen, rounded aggregate); (c) rutting, densification and plastic deformation of layers; (d) sags and humps, deep settlement or base distortion; and (e) waves, deep settlement or base distortion.

Another defect that is often measured is skid hazard, usually evidenced by polished aggregate or bleeding bitumen. It affects neither ridability nor structural adequacy of the pavement but it can be bad enough to require a resurfacing.

In airport pavements there are two additional probable causes for localized disintegration or surface erosion of flexible pavements--fuel spillage and jet engine blasts. Fuel spillage is a problem only where aircraft are refueled. Jet blast damage seldom occurs except from certain types of military aircraft whose engines exhaust directly onto the pavement.

In any detailed condition survey of a pavement structure, deflection measurements should be made to help determine the ability of the structure to carry the traffic using it. And, when there is evidence that faulty drainage has caused structural weakness, the drainage system should be examined and its adequacy noted.

A condition survey, then, can be superficial or integral. The present serviceability type of survey can be used preliminary to the detailed type of structural condition survey to eliminate from further study those sections that are performing well. This allows the engineer to concentrate on the sections that need further evaluation before improvements are made.

# Rigid Pavement Condition Surveys

W. E. TESKE, Paving Engineer, Portland Cement Association

•BEFORE rigid pavement condition surveys can be discussed intelligently, "pavement condition" should be defined.

To the general public—the average user—a definition might include such elements as the kind and degree of surface roughness, noise level, visibility, slipperiness, general appearance and the ability to handle the daily traffic demands. In other words, the average motorist is interested in those elements which affect his comfort and safety while he is on the road. Thus, an assessment of these and similar factors might constitute a satisfactory condition survey as far as the user is concerned.

For the engineer who specializes in traffic control, design, construction, maintenance, or safety, pavement condition may suggest many other measurable factors, the sum of which will help him make the right decisions in the future. Similarly, the administrators and operators of various highway systems must set policies which reflect the effect of overall economics, relating costs to capacities and land uses and needs. For example, placing restrictions on axle loads has the effect of prolonging the useful life of a pavement. Knowing the rate at which pavement life is diminished allows them to predict the future maintenance costs and to obtain the greatest returns from the initial investment.

Finally there are the researchers—people assigned to develop new methods and materials and who, through careful evaluation, provide information which will tend to hold costs to a minimum while supplying an adequate facility for the situation.

In general, each category would be satisfied with somewhat different information obtained from a pavement condition survey. So it is necessary to first establish the type and extent of information needed. The means available for obtaining this information and how much it will cost must be determined. Also, how often the surveys should be repeated and how the information should be reported must be anticipated.

Once these factors have been determined, the type of condition survey made will fall within one of the following classifications:

1. Reconnaissance.—This is a rather casual survey and requires a minimum of personnel and time. Such a survey usually precedes a more detailed study. Also, during periods of unusual weather it provides rapid information for estimating the amount and type of emergency maintenance work required.
2. Rating panels.—This classification requires a number of individuals working together under some established ground rules and subjectively rating pavements. The technique developed for the AASHO Road Test represents such a method.
3. Statistical.—This type of survey can be handled by a few persons equipped with counters and totalizing the number of times some pavement characteristic is observed. This can be done by driving slowly over a pavement. A crew can cover several miles of survey per day. Data thus accumulated are usually summarized as an average number of observations per unit of length of pavement, or the average distance between observations.
4. Semi-detailed.—In addition to the above information, this type of survey would include some general sketches of any unusual observations or conditions giving the approximate locations.
5. Detailed strip maps.—All observed details are plotted to scale and accurately located. Requires considerable time and effort.
6. Pictorial or photographic.—Takes special equipment but is relatively rapid. The data can be analyzed in the office.
7. Surface roughness measuring devices.—A number of various systems are available.

8. Investigational. —Permits a determination of causes of malfunctions of pavements. It usually requires detailed measurement and testing programs.

Obviously, each type of survey can be more or less complete. Most reasonably complete surveys of portland cement concrete pavements would include some measure of surface roughness, skid resistance, durability, adequacy of any special design features, and an indication of the structural adequacy of the design relative to the current traffic conditions.

Under "durability" would be noted the frequency and degree of such items as scaling, spalls, popouts, and "D" line and map cracking. Under "design" would fall such items as various types or kinds of joints, such as contraction, expansion, construction and longitudinal; type of load transfer units; and type and quantity of distributed reinforcement and the spacing between joints. With the various types of joints would be some indication of their condition. This would include such items as faulting, restraint cracking, condition of the seal, dowel condition, width of joint opening, and type and degree of pavement disintegration relative to spalling, scaling, raveling, "D" line cracking, or other manifestations of concrete disintegration. An indication of design and structural adequacy would be the presence or absence of some types of cracks, pumping or blowing, and faulting at joints and cracks.

In many instances, general condition surveys might result in scheduling special investigational surveys. These surveys would be conducted to develop sufficient data or information to isolate the cause or causes of unusual pavement performance. This might include a whole host of measurements of the concrete and underlying materials. These investigations can become quite laborious and expensive, and do not always result in an answer.

Unfortunately, the accumulation of field notes and data in themselves is not enough. These must be summarized and analyzed, and the results placed in the hands of individuals who can put them to use. Lack of communication all too often results in much useful and valuable information becoming lost or laid aside.

It is necessary to continually evaluate pavements in service, primarily to help determine their adequacy under continually changing conditions. The real test of new designs, new construction techniques, new materials and changing loading patterns, is how well full-scale models incorporating these elements perform under actual field conditions. Condition surveys thus become an important tool for evaluating these full-scale projects, and for providing the information necessary to make sound decisions.

# Analysis and Use of Condition Data in the Design of Pavements

FRANK P. NICHOLS, JR., Highway Research Engineer, Virginia Council of Highway Investigation and Research, Charlottesville

•PAVEMENT condition surveys have formed an integral part of the activity of the Virginia Council of Highway Investigation and Research every since its establishment in 1949. The methods used have undergone considerable evolution until the present scheme, in which condition survey data are used to compute a serviceability index, was initiated in 1961. The data are derived from measurements of cracking, patching, and rutting, as defined at the AASHO Road Test, and of riding quality as determined with Virginia's BPR type road roughness trailer. The expressions for PSI were developed by the Road Test staff after the Virginia trailer had been correlated with the AASHO profilometer on 26 sections of pavement, both on and off the AASHO Road Test site. These expressions are

Rigid pavements:

$$PSI = 14.30 - 5.15 \log \overline{VR}_{20} - 0.09\sqrt{C + P}$$

Flexible pavements:

$$PSI = 12.54 - 4.49 \log \overline{VR}_{20} - 0.01\sqrt{C + P} - 1.38\,\overline{RD}^2$$

or

$$PSI = 12.98 - 4.70 \log \overline{VR}_{20} - 0.01\sqrt{C + P}$$

in which

- PSI = present serviceability index (from 0 to 5.0),
- C = pronounced cracking in sq ft per 1,000 sq ft (flexible) or lineal feet per 1,000 sq ft (rigid),
- P = bituminous patching in sq ft per 1,000 sq ft, and
- $\overline{RD}$ = mean rut depth in both wheel paths (depth of depression under a 4-ft straightedge) in in.

A trial has been given to the use of continuous strip-film photography to facilitate measurement of cracking and patching. On flexible pavements the contrast between cracked or patched pavement and completely undistressed pavement was considered inadequate, and at present the C and P factors are estimated from visual examinations made at the same time roughness measurements are made. On rigid pavements, where the effect of cracking and patching on PSI is nine times as great, the contrast fortunately is more obvious, and it has been decided that the strip-film photography will continue to be used as a part of the pavement condition survey. A contract for this service on about 75 lane miles of concrete pavement in Virginia is being negotiated.

To insure against error creeping into the PSI values from changes in the behavior of the road roughness indicator, this machine is checked at frequent intervals over various sections of road which seem unlikely to undergo significant changes in roughness. The machine also is checked often against a similar machine built and maintained to high standards of accuracy by the Bureau of Public Roads' Physical Research Laboratory at Langley, Virginia.

Most of the pavement condition surveys made in Virginia have as their purpose the furnishing of information to help evaluate the success of certain typical pavement designs. Condition surveys may take various forms, but generally they are made with a view to one or more of the following considerations:

1. Smoothness, or riding comfort.
2. Structural adequacy, or ability to carry and continue to carry the loads.
3. Safety.

These three aspects might be termed the three S's of pavement condition.

To the designer, whose job it is to decide the type and thickness of pavement and select the component materials to be used in each given situation, the first two S's are of chief concern. The contribution of the pavement itself to safety is limited largely to its skid resistance, which is governed by the type and proportioning of materials used in the surface course rather than by structural adequacy as a whole. To the designer, then, pavement condition surveys should result in a rating (or ratings) to indicate both smoothness and structural adequacy; such ratings should not consider skid resistance because that factor, important as it is, normally is not the concern of the man charged with designing the pavement from the structural standpoint.

The present serviceability index (PSI) has been touted widely as being one of the most significant developments to have come out of the AASHO Road Test. The HRB Pavement Condition Evaluation Committee has taken note of this fact and has made plans to conduct a correlation study to compare a number of different methods of measuring pavement roughness. Such a study would attempt to evaluate the effectiveness of the various systems of obtaining objective measurements which might be used to compute "present serviceability."

But the designer's interest goes well beyond the present. He is also interested in future serviceability, and in this respect the "present serviceability index" concept falls short. The fully useful pavement condition survey, to the designer as well as to the maintenance engineer, must include a measure of the second "S," structural adequacy.

The presence of cracks and patches in the pavement would seem to offer evidence of deficiencies in the pavement's ability to carry its traffic load. The expressions for the computation of the present serviceability index, given earlier, do take into account to some extent the presence of cracking and patching, but in the case of flexible pavements the total possible impact on the PSI value due to these manifestations is only 0.3 in the scale from 0.0 to 5.0. Cases have been noted in Virginia in which rather severely cracked asphaltic concrete pavements have higher PSI values than certain brand new pavements with other types of bituminous surfacing which happen to have a poorer riding quality. One pavement in particular, though its PSI value was still in the "good" range, was so badly cracked that maintenance funds were obtained to apply a seal treatment, after the accomplishment of which the PSI value was found not to have risen but to have dropped appreciably. It is doubtful that the maintenance division could ever be convinced that this pavement was less serviceable after the seal was applied than before.

Foremost in the mind of the designer, as well as of the maintenance engineer, is a question not so much of how serviceable a pavement is now but how long it will retain adequate serviceability under the anticipated traffic loads. The function of a complete pavement evaluation has been quite aptly described in a Corps of Engineers manual, EM 1110-45-751, entitled "Airfield Pavement Evaluation Concepts." This manual states:

> The design of a pavement contemplates the use of materials with certain strengths, placed at certain thicknesses, and with the capability of carrying a given load. Because of variations ... strengths and thicknesses obtained in construction may be greater or less than those contemplated in the design. The purpose of an evaluation is to determine the physical properties of an airfield as actually built, or in its current condition, and to establish its load carrying capacity for various aircraft types.

Such a determination obviously requires a more complete condition survey than would be required merely to obtain a present serviceability index.

Questions before this forum are, then, how best can a complete evaluation be accomplished? Should not a pavement condition survey provide measurements of present strength as well as present serviceability? How can plate bearing tests or pavement deflection measurements, made both on the surface and perhaps at the interfaces of the various layers, be used to evaluate structural adequacy? And, finally, can the joint contributions of riding quality, visible defects, and measurable strength be integrated into a single index of pavement adequacy?

# Pavement Maintenance

ALFRED B. MOE, Manager, Maintenance Engineering Branch, Bureau of Yards and Docks

•THE subject of maintenance has been a major item in many pavement seminars, conferences, and meetings in the past. In spite of all that has been said for it, and about it, there is still an urgent need for improvements and a substantial degree of standardization in the maintenance area.

To keep the pavements of national and state highway systems and airfields in a continuous serviceable condition at a reasonable expense, a definite plan of action must be developed and energetically followed by all concerned.

Unfortunately, the pavement maintenance problem is not simple. Many factors are involved that affect the performance and deterioration of a pavement. The extent and type of the maintenance that will be required for any particular pavement will depend on a number of conditions: the traffic system to which the pavement is subjected; climate; the structure of the pavement; the quality of construction; the frequency and extent of inspection performed, both during construction and during maintenance; engineering talent involved; maintenance practices; discipline; and money; not necessarily in that order. This sounds like a collection of words and phrases but this list of items is discussed one at a time and in a little more detail in the following.

Pavements are designed to carry traffic of various types, with safety and comfort, and with a minimum of detrimental effects to vehicles or to the pavement itself. Current evaluation of pavement performance is based on the relative ability of these pavements to serve traffic over a period of time. Although the definition of performance varies with the design engineer, performance is generally related to the quality of the "ride" of the vehicle over the road, street, or runway. Therefore, there must be a basic understanding of the traffic system utilizing the pavements, whether it is automotive vehicles or aircraft, in order to plan and provide maintenance necessary for satisfactory performance.

Considerable research is being performed to obtain or develop theories that will permit a realistic prediction of road life from the characteristics of traffic flow. The pavement serviceability-performance concept developed during the AASHO Road Test is a firm step in this direction. The Performance Index or rating that can be derived under this concept for a particular pavement could be used objectively to determine priorities for maintenance or reconstruction of that pavement; however, it does not lend itself directly to the prediction of future performance. Because serviceability is defined relative to the intended use of the pavement, the pavement profile must be kept as smooth as possible to minimize the road loading mechanics that affect road life, vehicle life and driver fatigue. Smoothness must not be maintained at the expense of slipperiness.

The traffic, itself, affects maintenance in another way; work must be accomplished during periods of low traffic density, or means of bypassing the work area must be used. In either case, safety measures of varying degrees of complexity must be taken to protect the crews and equipment engaged in the work.

Climatic conditions play an important part in the maintenance program. In spite of standardized inspection and maintenance procedures, and probably because of them, the variable effects of climate are often surprising and unpredictable. How severe these effects will be is usually determined by the quality of maintenance being performed. In the winter of 1962, in the Washington area, unusually severe temperature and icing conditions played havoc with streets and roads. Some of the damage was directly attributable to poor maintenance. Cracks in concrete as well as flexible pavements had been left unattended or haphazardly patched. Undisciplined use of snowclearing machinery and careless or inexperienced crews created further damage. Therefore, streets and roads that could have been restored by minor repairs often had to be replaced.

In the last decade, the weather has taken some peculiar twists. Southern states have experienced snow and frost and many northern states have had light winters. Other sections of the country, normally dry or experiencing light rainfall, have been deluged, whereas some of the "rainier" areas have been almost arid. All of this affects pavements because the usual maintenance practices in these areas were not geared to these unexpected conditions.

It is impossible to "crystal ball" freak storms or unusual weather conditions that occur only once or twice in a generation. To maintain for all possible eventualities would result in such over-maintenance that it could not be justified. However, sufficient unusual weather phenomena have occurred that justify taking certain additional precautionary measures in maintaining pavements to minimize damage from unforeseen bad weather. Keeping the pavements sealed against water infiltration, a little extra care in keeping the drainage systems open and working, keeping shoulders dressed and stable, using base and subgrade materials that are less susceptible to frost damage, and making repairs properly when they are needed often mean the difference between minor damage and costly failures.

The weather, itself, does not always create the damage. Pavements have been damaged by snow-cleaning crews or by de-icing chemicals. Snow-removal equipment has scarred surfaces sufficiently to start or accelerate spalling or surface scaling, has damaged joints and joint materials in rigid pavements, or has damaged seal coats on flexible pavements. But salt is not always bad. Maintenance engineers, in certain areas, have successfully used sodium chloride stabilization to reduce effectively the freezing and thawing effects on paving over frost-susceptible soils and subgrade materials. One of the greatest challenges to the maintenance engineer is the problem of keeping his roads, streets or runways in such condition that unusual weather, particularly weather foreign to his area, will create the least distress.

A pavement structure is designed to spread out the applied load to the extent necessary to avoid failure of the basement soil or to bridge over soils of inadequate support or localized weakness.

The retention of the structural integrity of the pavement is the direct responsibility of the maintenance engineers and the maintenance force. A properly designed and constructed pavement structure should be easy and economical to maintain, provided adequate protective measures are carried out and the traffic loads do not appreciably exceed the load criteria used in the design. Protection means joint and crack cleaning and resealing, patching spalled areas, seal-coating, keeping the drainage system operable, and other work necessary to reduce the effects of wear and tear and weather. The maintenance engineers should be familiar with the structure of all sections of paving so that the pavement can be kept in an acceptable serviceable condition at all times through normal maintenance practices.

The structure is only as good as the quality of its construction. Many excellent designs are sabotaged by poor-quality construction and many conditions influence quality. The design may be purposely altered, due to a lack of funds, and a marginal rather than an adequate pavement may result. Contractors who are not fully qualified to perform first-class paving work, or who are careless and sometimes a little dishonest, can produce low-quality pavements. In addition, honest mistakes are often made and undetected during construction. Furthermore, the quality and adequacy of supervision and inspection have their impact on the end result.

A pavement of marginal or poor quality will quickly show signs of distress. The first signs may be subtle and difficult to notice. But, maintenance engineers must be on the alert for these signs and take immediate and appropriate action to arrest or reduce the deterioration of these pavements.

Inspection is one of the most important phases of construction and subsequent maintenance. Only topnotch qualified and knowledgeable inspectors can insure pavement performance according to plans or expectations. The inspector can be, and often is, the Achilles heel of the whole pavement program. If he performs his job honestly and effectively during construction, the pavement will be constructed as designed and will be destined for a long, useful and low maintenance life. If he follows through with the same efficiency after the pavement is in service, maintenance costs will be low and the pavement will continue to perform as expected. Only that maintenance actually required will be performed and traffic will flow with a minimum of interruption or discomfort.

Good inspectors, particularily maintenance inspectors, are in short supply. During new construction, the inspector usually has sufficient guides in specifications, drawings, and established procedures to assist him in determining whether the work is being performed satisfactorily. Even then he must have a deep sense of responsibility regarding the technical features of the specifications. When making maintenance inspections, he often has to depend largely on his experience and ability to see and recognize signs of inferior pavement performance or abnormal behavior, and from these signs, to determine the probable causes of failures or deficiencies. The timeliness, magnitude and cost of maintenance will largely depend on how expertly he performs his duties. His observations will be included in condition surveys that will be further analyzed by maintenance engineers who will decide on the work to be done and who will program it accordingly. Considerable time can be saved in the maintenance program if the inspector's reports are properly described, clear, and concise, and if his analyses are dependable.

Maintenance planning is not a job for a laborer or repairman although these trades are necessary in the program. Good engineering talent is required to back up the program and keep it working for the benefit of all concerned. The cost of salaries for professional personnel is but a drop in the bucket compared to pavement maintenance costs. A maintenance staff composed of well-qualified and experienced engineers will more than justify its existence. Men who know materials, pavement design, construction, soils, and drainage and who can quickly recognize signs of distress and know what remedial measures are necessary, can control, effectively and economically, a pavement maintenance program of considerable scope.

Once a road, street, or airfield pavement has been completed, the maintenance program begins. The maintenance practices that are carried out will determine the success or failure of the program. It is true that few programs fail, but some of them come close to it because they are wasteful and relatively ineffective. A program that encompasses a system of records or an inventory of pavement structures, regular condition surveys, and prompt remedial action when signs of distress are first noticed (provided they are noticed early), will keep pavements serviceable throughout their estimated life.

A good pavement inventory in which the road, street or runway system is subdivided into homogeneous sections for observation and evaluation is invaluable to the maintenance program. These sections can be categorized by underlying or basement soil, construction type, age, design, materials, etc., as suggested by the Canadian Good Roads Association, or in any other form that will facilitate the use of the inventory in the program. Data sheets and condition survey reports kept with the inventory provide a current status report of pavements.

Condition surveys can be made by any one or several of the many "observation" systems available. The simplest survey is made by a "walk-over" inspection of the pavement section, visually observing its condition and recording what is seen on a form or data sheet. This is tedious and time-consuming and depends on the conscientiousness and experience of the individual making the observations and the care he takes in making his notes.

Equipment that travels over the pavements at fairly good speeds, and which records the characteristics of the surface on tape by instruments, provides rapid accumulation of data that can be analyzed in the engineering office. Comparison of tapes taken over separate intervals of time gives an indication of the behavior of the pavement.

Photographic systems that take continuous strip films or successive pictures provide still another method of obtaining data on the condition of the pavement. None of the present methods of surveying pavements provides all the information necessary to plan and carry out the maintenance program. However, a combination of them does provide sufficient data, in most cases, so that the maintenance engineer can effectively study and evaluate the condition of his pavements to a major extent in his office. These condition surveys, incidentally, can also be used to police the maintenance program because they will give an indication of the relative behavior of the pavements in the various sections of the inventory which should further indicate the quality of maintenance being performed.

The end product of the proper use of inventories and condition surveys is taking appropriate remedial action. Aggressive, continuing and appropriate action is the key to the maintenance problem. This is knowing what to do, how to do it, and then doing it. The same meticulous attention to detail must be given to the engineering of maintenance and repairs that is given to the original design. And speaking of design, all causes of deficiencies and failures must be reported to the design engineers to assist them in reducing the maintenance potential in future designs.

The methods by which maintenance can and should be accomplished are too copious to cover in this paper and no attempt has been made to do so. It would be impossible to do more than scratch the surface and even then, it would be difficult to make a choice as to what methods should be included.

The Highway Research Board, the American Society of Civil Engineers, the Asphalt Institute, the Portland Cement Association and many similar organizations have prepared and issued a considerable number of papers, articles, reports, manuals or publications outlining or recommending up-to-date methods and materials for maintaining or restoring pavements. Maintenance engineers should read, study, evaluate and utilize them in order to carry out a more aggressive maintenance program.

Discipline is nothing more than subjecting oneself to a particular code of behavior or practice, in this case, good established and progressive practices of pavement maintenance. This does not mean that one should go strictly by the book at all times. It means that one should adhere to methods and materials proved successful, but should be alert and recognize new and more effective materials, methods, tools, designs, analyses, and programing techniques. No lesser course of action should be taken than that prescribed for a particular situation, however, until careful consideration has been given to all the conditions involved.

It is so easy to prescribe design criteria, and to recommend construction, inspection, and maintenance practices, but all of this costs money. If all needed money was readily available to construct roads, streets, and runways, to hire competent inspectors and professional personnel, and to maintain these pavements in perfect condition, there would not be so many problems. Obviously, the ideal situation is to have adequate, qualified personnel; unquestionable design criteria; good and reasonable construction costs; and adequately budgeted and funded maintenance programs.

The degree of honesty, efficiency and conscientiousness, and the amount of necessary funds to reach this ideal situation are unfortunately lacking or impossible to obtain. Therefore, in order to have the best maintenance program possible, it will be necessary to:

1. Staff the maintenance division with the most competent and experienced engineering and maintenance personnel that can be obtained.
2. Prepare and keep records of all pavement structures that are as precise as possible for each maintenance district. These should include records of subgrade soils, subbase and base courses, wearing courses, drainage systems, safe load-carrying capacities, and any other information necessary to complete the data.
3. Establish a pavement condition survey program to check appropriately and record the physical condition of the pavements at regular intervals.
4. Make systematic reviews and analyses of the condition survey reports.
5. Review periodically, current maintenance methods to make sure that they are being carried out as specified or to determine whether improved methods are needed.
6. Prepare job orders or projects for preventive maintenance and to correct deficiencies revealed by the studies of condition survey and trouble reports. (Each project or job order must contain a complete description of the work to be performed.)
7. Review the job orders and projects and assemble them into suitable programs by priorities determined by the urgency of the work.
8. Develop realistic budgets to cover adequately these programs and be sure that the price of each project covers the package.

9. Schedule contracts or work to accomplish the projects under the most favorable conditions of weather and traffic and, if possible, when contract costs are most reasonable.

It is difficult to discuss the subject of pavement maintenance without repeating information that is thoroughly familiar to people who are actively engaged in this work. However, in the course of presenting this information something may be said that will provide additional food for thought or that will motivate or challenge someone to put a little more effort into improving or perfecting some phase of his maintenance program. The reason that certain items are mentioned over and over again is that some programs are still lagging and maintenance practices and methods are not keeping pace with the pavement performance demanded by present-day traffic or which are estimated to be required to meet future traffic conditions.

Satisfactory maintenance can only be obtained through constant research, aggressive action, and the combined efforts of all concerned.

Establishing a good system of surveying and recording the condition of the pavements, keeping good records, carefully analyzing the data, and then using the information obtained from the surveys properly and to the maximum extent, will provide a solid foundation for a successful pavement maintenance program.

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# Use of Pavement Condition Data to Predict Vehicle Behavior

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•THE prediction of vehicle performance from pavement condition is made very frequently. The American public, equipped with a free road map from the corner service station and uninitiated in the ways of higher mathematics, deduces from this map the probable behavior of the family vehicle on a prospective road. The route of the family vacation trip is therefore usually planned so as to avoid unimproved roads and to make maximum use of the new Interstate Highway System wherever available. The pavement condition evaluation that is used in this instance is not precise, and the resulting estimate of vehicle behavior is not generally expressed in numbers of several significant figures, but it is evident that an estimate of vehicle behavior is made.

There are, however, those individuals who are interested in a more accurate evaluation of vehicle behavior. These investigators, usually dealing with problems pertaining to either highways or vehicles, generally have two main areas of interest in this regard. One group is interested in the effect of the pavement on the vehicle, whereas the other group is interested in the effect of the vehicle on the pavement.

## EFFECT OF PAVEMENT ON VEHICLE

It is interesting to consider various investigations currently being conducted in which the effect of the pavement on the vehicle is of primary concern.

A detailed description of a research activity conducted by the General Motors Corporation has appeared in recent publications. This company has developed a ride simulator in which it is possible for an individual to experience the ride which a passenger vehicle would produce traveling at a selected velocity over a selected highway. An automobile body with the associated suspension system is mounted on servo units so that the effect of the highway on the wheels of the vehicle is carefully reproduced. Without leaving the laboratory it is therefore possible for these investigators to study the effect of different shock absorbers and other suspension components on the riding qualities of the vehicle, and to investigate the changes that result when these components are modified. In this case knowledge of the condition of the pavement is needed to study the riding qualities of the vehicle.

The users of both commercial and military aircraft are also interested in the effect of pavement condition on the behavior of their aircraft. Before take-off and after landing it is necessary to maneuver aircraft on pavements. Under certain conditions of pavement profile and taxiing speed it is sometimes possible to build up large amplitudes of wing vibration due to resonance of the wing structure with disturbances from the pavement. Excessive vertical motion of the wings of an airplane produces high stresses in the wing structure and is detrimental to the aircraft. Investigators in this area have therefore been concerned with minimizing these stresses and have been compelled to consider the condition of the pavement over which the aircraft moves as well as the characteristics of the aircraft. In this situation knowledge of the condition of the pavement is needed to study the response of the wing structure.

The aerospace industry has also shown an interest in pavement condition data. This industry has been charged with the responsibility for supplying ground transportation for the missiles that they manufacture. It may seem surprising, but certain types of missiles are really very fragile, and can easily be damaged when moved from one location to another. Because of this, it is usually necessary to design a special suspension system that will protect the missile from shock and vibration during the time that it is being transported. Engineers associated with this problem are therefore concerned with pavement condition as a factor causing damage to missiles when carried by a ground transport. Less glamorous industries are also concerned with the relationship between pavement condition and damage to their products in transit.

It is also interesting to note that the effect of the pavement on the vehicle has been taken as a criterion of pavement condition by W. Drake from Kentucky. He has located accelerometers on a passenger seated in a vehicle and has measured these accelerations as the vehicle moves over the highway in question. In this case the effect of the pavement on the passenger is taken as an indication of the condition of the pavement. In passing it should be noted that theoretically it should be possible to predict the accelerations that the passenger will experience if the proper pavement evaluation information is available together with the necessary vehicle characteristics.

## EFFECT OF VEHICLE ON PAVEMENT

The effect of the vehicle on the pavement has been of concern to investigators whose primary interest is the pavement itself. Just as the pavement can exert large forces on the vehicle, so can the vehicle exert large forces on the pavement. This is evident when one considers a pavement that contains large faults and potholes. Large forces can also be developed, however, when the pavement surface does not contain sharp discontinuities. Smooth undulations in the highway can result in large forces between highway and vehicle under certain conditions.

The theoretical prediction of the force that a vehicle exerts on the pavement has been undertaken by certain investigators. A mathematical model of the pavement-vehicle system has been developed at the Cornell Aeronautical Laboratory. This model makes possible the study of this problem with the aid of modern computing methods, and estimates of the force that the vehicle exerts on the highway have been obtained as well as other information.

At Purdue University the theoretical prediction of the vehicle forces exerted on the pavement has been approached in a somewhat different manner. Experimentally determined vehicle characteristics have been combined with statistical descriptions of pavements (elevation power spectra) to obtain statistical estimates of the forces (force power spectra) produced by the vehicle. Experimental measurements of these forces indicate that at the present time the predicted forces are larger than those actually encountered. This investigation also includes the measurement and prediction of stresses and deflections in the pavement resulting from these dynamic vehicle loads.

Measuring the dynamic force that the vehicle exerts on the pavement has been undertaken by several organizations including the Bureau of Public Roads, the Michigan State Highway Research Laboratories at East Lansing, and by the AASHO Road Test. A successful procedure for doing this has resulted in which continuous records of tire pressure are taken and are then converted to force measurements.

The results of both the theoretical and the experimental investigations in this area indicate that the rougher the surface of the pavement, the larger the force that is usually produced on the highway by the vehicle. It is thus evident that the condition of the pavement influences the forces to which the pavement is exposed, and it may be that the condition of the pavement is related to the amount of future service that it may give.

## CONCLUSIONS

It is therefore seen that the appropriate pavement condition data can be used to estimate the effect of the vehicle on the highway as well as the effect of the highway on the vehicle. The most commonly used criterion of pavement condition for this purpose to date has consisted of highway elevation measurements, usually taken with a rod and level. The difficulties involved in obtaining and using these data to describe the condition of the pavement are obvious. This information is time-consuming and expensive to obtain and is invalid after the winter frosts have changed the pavement profiles. For many of the investigations previously discussed this information, however, has served as the sole criterion of pavement condition.

Other devices are fortunately being developed to obtain pavement condition data that may be equally acceptable. The truck-mounted profilometer, used by Housel, has potentialities in this regard. In addition, a special profile measuring device, described at the Annual Meeting in 1962 by respresentatives of the General Motors Corporation, appears promising. Likewise, the AASHO slope profilometer may also be useful for obtaining pavement condition data that can be used in the investigations just discussed.

In conclusion it should be emphatically stated that there is a pressing need for a fast, cheap way of accurately measuring the characteristics of a pavement that influence the behavior of a vehicle. These measurements should be of such a nature that they can be used, together with the proper vehicle characteristics, to predict the desired vehicle performance.

# Serviceability Ratings of Highway Pavements

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•SEVERAL years ago D. C. Greer, State Highway Engineer of Texas, made the statement that highways are for the comfort and convenience of the traveling public. This simple statement implies that the purpose of any road or highway pavement is to serve the highway user and that a good highway pavement is one on which the traveling public has a comfortable ride. But what is a comfortable ride? And how can the comfort and convenience provided by a highway pavement be measured? These are some of the unanswered questions which plague the highway authority when the final decision as to which highways to improve must be made.

For many years state highway departments have developed reconstruction and maintenance programs on the basis of the personal knowledge of members of their staffs relative to the needs of their highway systems. However, highway personnel usually have different amounts of information on the condition of each highway within the highway system and, thus, their evaluation of the serviceability of a specific highway pavement may be heavily biased. It is also typical that a poor highway pavement to one engineer might mean that the pavement has a few cracks, whereas to another it might mean that a large number of cracks and patches are present. One engineer might classify a highway pavement with 10-ft lanes as excellent, whereas another might classify only highway pavements with 12-ft lanes in the excellent category. As a result, it is difficult to compare evaluations made by different personnel, and almost impossible to develop optimum reconstruction and maintenance programs on the basis of such evaluations of highway pavement serviceability.

It is often true, however, that one pavement at any one time is performing its services better than another. Questions then are raised: How much better? How can an adequate comparison be made? What is needed is a simple, accurate and economical method of evaluating pavement serviceability.

Such an evaluation procedure might be one which would utilize an objective measurement or measurements and which would have a close correlation with the subjective human judgment of the total traveling public. Such a procedure should also provide an indication of the performance of a pavement throughout its life if evaluated periodically, be applicable to all roads, and be usable as a tool in developing final highway improvement programs.

Many studies have been devoted to the problem of the evaluation of highway pavement serviceability and/or performance. Various evaluation procedures have resulted from these studies and are being used by state highway departments throughout the country. These procedures may be classified into three general types: (a) evaluation by sufficiency rating systems, (b) evaluation by surface riding quality indicators, and (c) evaluation by subjective serviceability ratings. The latter two types of procedures were the subjects of this research.

## PURPOSE AND SCOPE

This study was first of all concerned with the evaluation by the traveling public of the present serviceability of highway pavements and its desirable level and with the ability of highway and other personnel to estimate such ratings of present serviceability. It was also concerned with road roughness, as measured by the standard Bureau of Public Roads roughometer, as a method for the objective determination of the present serviceability of pavements.

The purposes of this study were (a) to determine the correlation of present serviceability ratings made by experts in the field of highway engineering with similar ratings made by typical road users, (b) to determine the correlation of roughometer measurements with present serviceability ratings, and (c) to attempt the development of a simple, economical evaluation procedure which would accurately rate the serviceability of highway pavements.

Sixty pavement sections located within a 40-mi radius of Lafayette, Ind. were studied. The pavement sections varied in length from 0.5 to 12.75 miles, averaged five miles, and totaled approximately 300 miles. Nineteen of the sections were rigid pavements; 22 were rigid with bituminous overlay; and 19 were flexible pavements. All types of pavement condition—from excellent to very poor—were included in each surface type.

The test sections were basically state highway designated maintenance sections and

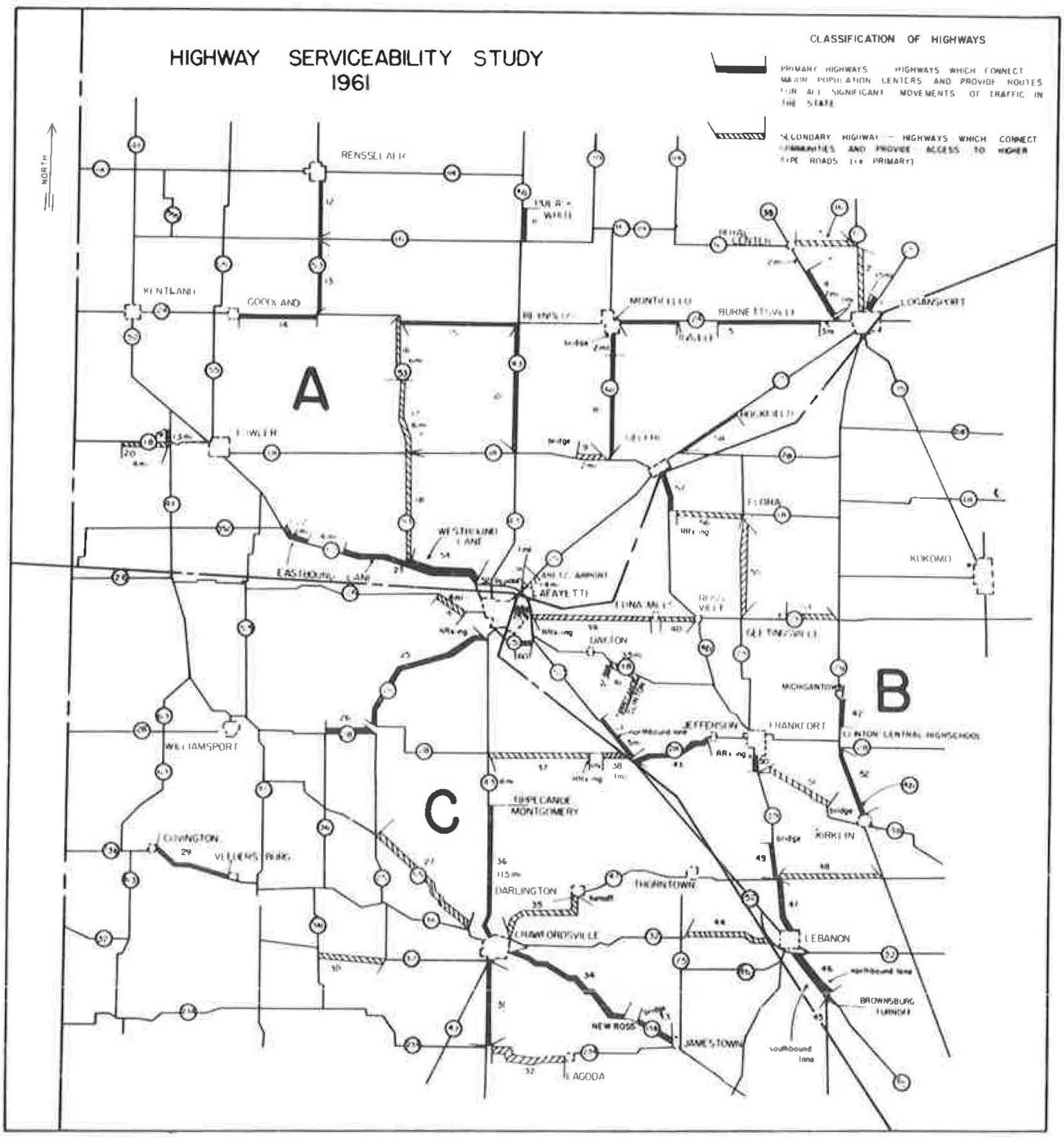



Figure 1. Location of the pavement sections.

their location is shown in Figure 1. They were identified to the members of the rating panels only as primary highways or secondary highways. The information as to whether the pavement was rigid, rigid with overlay surface, or flexible was not provided the raters, although many of them were capable of noting this information while rating.

## PROCEDURES

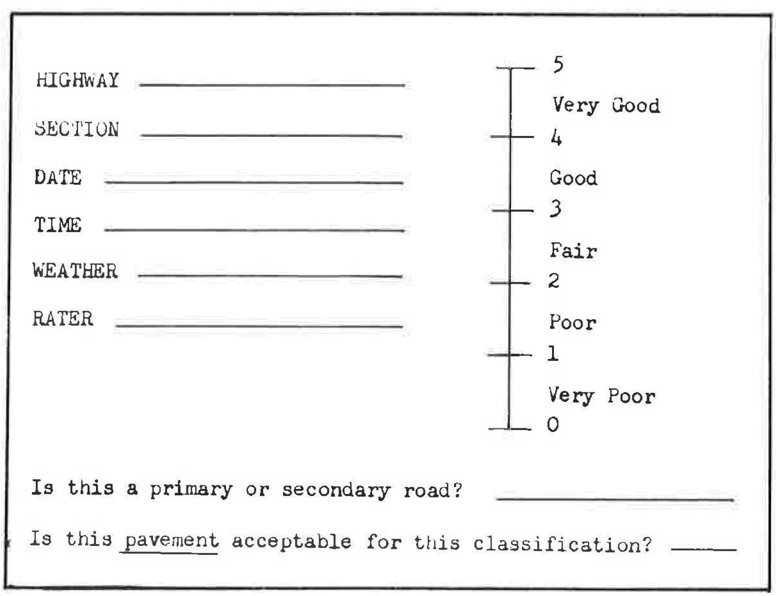
### Selection of the Panels of Raters

The 60 pavement sections were rated by three panels of raters with ten raters in each panel. Two of the panels were composed of professionals in the field of highway engineering. One of these was composed of engineers from the Indiana State Highway Commission; the second was composed of staff members of the Purdue University School of Civil Engineering; and a third panel was composed of laymen who were randomly selected as typical road users.

The members of the State Highway panel were selected by officials of the State Highway Commission from their engineering personnel. All such personnel were from the central office in Indianapolis or from the Crawfordsville district (the district serving the Lafayette area). They represented such highway interests as planning, road design, road construction, bituminous construction, maintenance, and traffic engineering. The ages of these men ranged from 31 to 62 years with 53 being the mean age. Driving experience ranged from 15 to 45 years and they averaged 30,700 miles annually.

The members of the Purdue panel were selected from the staff of the School of Civil Engineering at Purdue University. Those selected were from the Transportation staff or from an area directly related to transportation. Members represented such areas as pavement design, structures, soils, bituminous materials, air photos, planning and research. The ages of the men ranged from 34 to 56 years with 41 being the mean age. Driving experience ranged from 15 to 46 years with a mean of 25 years; and annual driving mileage ranged from 9,000 to 20,000 miles with a mean of 12,900 miles.

The lay panel was selected in a random manner from the Lafayette and Purdue University telephone directories, and consisted of seven men and three women who were assumed to be typical road users and representative of the traveling public. The


HIGHWAY ______
SECTION ______
DATE ______
TIME ______
WEATHER ______
RATER ______

5
Very Good
4
Good
3
Fair
2
Poor
1
Very Poor
0

Is this a primary or secondary road? ______

Is this pavement acceptable for this classification? ______

Figure 2. Rating card.

occupations of the raters were student, graduate-staff member, plant supervisor, professor of electrical engineering, welder, tavern manager, truck driver, housewife, housewife-former school teacher, and school nurse. The ages of these raters ranged from 23 to 53 with 38 being the mean age. Driving experience ranged from 4 to 35 years with a mean of 19 years; annual driving mileage ranged from 2,000 to 20,000 miles with a mean of 7,800 miles.

Rating Instructions

Each rater in this study was individually instructed. This was done to keep each rater from being influenced by the other raters, and it was felt that rater response would be better under individual instruction. That is, the rater, if in doubt about any aspect of the instructions, would be more likely to ask questions, and it was very important that the raters clearly understood the "rules of the game." All raters were given identical instructions including a discussion of the general purpose and scope of the study.

Each rater was also instructed always to keep the following question in mind when rating each pavement section: If I were to ride over this pavement section regularly for the appropriate purposes, how well would it serve me? The raters were told that for secondary highway pavements the use would be primarily short trips, with purposes such as to work or to town, whereas for primary highway pavements some longer trips would be included with such purposes as business and vacation.

It was also stressed that the serviceability of the pavement only was to be rated. All features not part of the pavement itself, such as right-of-way and median width,

TABLE 1

SUMMARY OF PRESENT SERVICEABILITY RATINGS
RIGID PAVEMENT SECTIONS

| Pavement Section and Class. | Length | Mean Serviceability Ratings | | | | Roughness Index (in./mi) |
|---|---|---|---|---|---|---|
| | | ISHC | Purdue | Laymen | PSR | |
| 1 P | 1.25 | 2.7 | 2.8 | 2.5 | 2.7 | 128 |
| 4 P | 6.50 | 2.6 | 2.6 | 2.3 | 2.5 | 129 |
| 7 P | 1.75 | 2.6 | 2.4 | 2.2 | 2.4 | 116 |
| 17 S | 4.75 | 2.4 | 2.2 | 2.2 | 2.3 | 128 |
| 18 S | 8.75 | 2.6 | 2.6 | 2.4 | 2.6 | 124 |
| 19 P | 1.25 | 1.3 | 1.3 | 1.5 | 1.4 | 175 |
| 21 P | 4.50 | 3.1 | 3.1 | 3.0 | 3.1 | 115 |
| 22 P | 1.75 | 3.8 | 4.1 | 4.0 | 4.0 | 89 |
| 23 P | 11.00 | 3.3 | 3.6 | 3.3 | 3.4 | 99 |
| 28 S | 1.00 | 4.1 | 4.0 | 3.7 | 3.9 | 87 |
| 45 P | 3.25 | 4.4 | 4.7 | 4.2 | 4.4 | 85 |
| 46 P | 3.25 | 4.6 | 4.6 | 4.4 | 4.5 | 91 |
| 47 P | 3.75 | 4.4 | 4.3 | 3.9 | 4.2 | 90 |
| 49 P | 2.25 | 4.2 | 4.1 | 4.0 | 4.1 | 91 |
| 50 P | 2.25 | 4.3 | 4.3 | 3.9 | 4.2 | 75 |
| 54 P | 5.50 | 3.4 | 3.2 | 3.1 | 3.2 | 107 |
| 57 P | 2.00 | 3.0 | 2.9 | 2.7 | 2.9 | 112 |
| 59 P | 0.50 | 1.4 | 0.9 | 1.0 | 1.1 | 237 |
| 60 P | 0.75 | 2.4 | 2.3 | 2.5 | 2.4 | 132 |
| Subtotal | 66.00 | 60.8 | 60.0 | 56.8 | 59.3 | 2,210 |
| Type mean | 3.50 | 3.2 | 3.2 | 3.0 | 3.1 | 116 |

grade, alignment, and shoulder and ditch conditions, were not to be considered in the rating of the pavement section. The raters were also instructed to rate only the existing condition of the pavement section.

Each rater was requested to drive over the pavement sections in a vehicle similar to one that he normally drove. He could ride over the pavement sections at any speed he desired, but rating was not to be done during rain or other inclement weather conditions. It was also stressed that the rater was to travel alone and work independently. It was very important the the rater not be influenced by the opinions of others.

Each rater was instructed to rate the serviceability of each pavement section on a 0 to 5 point rating scale (Fig. 2) by marking on the vertical scale a horizontal line at the value he felt was the serviceability rating of that pavement. One card was used for each pavement section by each rater. He was also instructed to state the acceptability (Yes or No) of each pavement section, after noting its highway classification. The rater was also required to observe the 60 pavement sections in a specified order. The rating of the 300 miles was done by each rater over three days, not necessarily consecutive, and for statistical randomizing purposes, different travel routes were followed by each rater within each panel but with one rater in each panel being assigned the same route.

TABLE 2

SUMMARY OF PRESENT SERVICEABILITY RATINGS OVERLAY PAVEMENT SECTIONS

| Pavement Section and Class. | Length | Mean Serviceability Ratings | | | | Roughness Index (in./mi) |
|---|---|---|---|---|---|---|
| | | ISHC | Purdue | Laymen | PSR | |
| 2 S | 6.00 | 2.0 | 2.6 | 2.4 | 2.3 | 167 |
| 5 P | 7.75 | 2.7 | 2.2 | 2.3 | 2.4 | 93 |
| 6 P | 4.25 | 2.6 | 2.2 | 1.9 | 2.2 | 98 |
| 8 P | 7.50 | 3.0 | 3.1 | 3.3 | 3.1 | 89 |
| 10 P | 9.25 | 3.1 | 2.7 | 3.1 | 3.0 | 105 |
| 11 P | 3.00 | 4.1 | 4.0 | 4.2 | 4.1 | 75 |
| 12 P | 3.75 | 3.6 | 3.6 | 3.9 | 3.7 | 80 |
| 13 P | 6.50 | 3.6 | 3.6 | 3.6 | 3.6 | 87 |
| 14 P | 6.50 | 2.9 | 2.9 | 2.8 | 2.8 | 85 |
| 15 P | 8.25 | 2.7 | 2.5 | 2.8 | 2.7 | 98 |
| 16 S | 4.50 | 2.4 | 2.4 | 2.4 | 2.4 | 154 |
| 25 P | 12.75 | 3.8 | 3.5 | 3.3 | 3.5 | 91 |
| 26 P | 3.50 | 3.9 | 3.8 | 3.9 | 3.9 | 76 |
| 29 P | 5.75 | 3.9 | 3.9 | 3.5 | 3.8 | 79 |
| 31 P | 2.50 | 4.0 | 4.0 | 3.4 | 3.8 | 73 |
| 34 P | 9.00 | 3.1 | 3.0 | 3.0 | 3.0 | 91 |
| 36 P | 10.75 | 3.9 | 3.9 | 3.6 | 3.8 | 88 |
| 38 S | 0.50 | 2.7 | 3.0 | 3.2 | 3.0 | 114 |
| 42 P | 1.50 | 2.6 | 2.6 | 2.6 | 2.6 | 92 |
| 43 P | 2.50 | 2.5 | 2.5 | 2.6 | 2.6 | 106 |
| 52 P | 5.25 | 3.7 | 4.0 | 3.8 | 3.8 | 85 |
| 58 P | 4.25 | 4.0 | 4.2 | 4.1 | 4.1 | 82 |
| Subtotal | 125.50 | 70.8 | 70.2 | 69.7 | 70.2 | 2,108 |
| Type mean | 5.70 | 3.2 | 3.2 | 3.2 | 3.2 | 96 |

# DISCUSSION OF RESULTS

## Panel Rating Values

A summary of the rating data obtained by the three panels for each pavement section is given in Tables 1, 2, and 3 for rigid, rigid-overlay, and flexible pavement sections, respectively. Pavement section numbers may be found adjacent to the sections in Figure 1. The mean of all 30 ratings for each section was assumed to be the present serviceability rating (PSR) for that section. It can be seen from these three tables that there were no marked differences between the ratings of each panel or between the PSR's and the mean ratings of each panel.

## Analysis of Variance

A mixed model, cross-classified nested analysis of variance (ANOV) design was utilized to analyze the rating data. Basically, the ANOV consists of classifying and cross-classifying data and testing whether the means of a specified classification differ significantly. In this way the highway serviceability ratings made by experts in the field of highway engineering could be tested for a significant difference from the highway serviceability ratings made by typical road users. Also, the means of the individual raters within each of the rating panels could be tested.

The assumptions which underlie this method include: homogeneity of variances, normal distribution of errors, fixed pavement type and panel type, random pavement section samples within each pavement type, and random rater samples within each panel type. Because one of the desired analyses required an equal number of pavement

TABLE 3

SUMMARY OF PRESENT SERVICEABILITY RATINGS
FLEXIBLE PAVEMENT SECTIONS

| Pavement Section and Class. | Length | Mean Serviceability Ratings | | | | Roughness Index (in./mi) |
|---|---|---|---|---|---|---|
| | | ISHC | Purdue | Laymen | PSR | |
| 3 S | 5.75 | 2.1 | 2.3 | 2.1 | 2.2 | 116 |
| 9 S | 1.75 | 2.5 | 2.3 | 2.6 | 2.5 | 134 |
| 20 S | 3.75 | 2.7 | 2.9 | 3.1 | 2.9 | 139 |
| 24 S | 3.75 | 2.8 | 3.1 | 3.0 | 2.9 | 110 |
| 27 S | 10.50 | 1.3 | 1.8 | 1.5 | 1.5 | 144 |
| 30 S | 5.00 | 2.7 | 2.5 | 2.8 | 2.7 | 155 |
| 32 S | 5.50 | 3.5 | 3.6 | 4.0 | 3.7 | 87 |
| 33 P | 3.25 | 4.1 | 4.2 | 3.9 | 4.1 | 62 |
| 35 S | 7.00 | 2.7 | 3.1 | 3.0 | 2.9 | 103 |
| 37 S | 8.50 | 2.1 | 2.3 | 2.4 | 2.2 | 152 |
| 39 S | 9.50 | 3.2 | 3.3 | 3.1 | 3.2 | 92 |
| 40 S | 3.00 | 2.3 | 2.7 | 2.9 | 2.6 | 110 |
| 41 S | 3.25 | 1.6 | 2.1 | 2.3 | 2.0 | 144 |
| 44 S | 6.75 | 3.7 | 3.7 | 3.7 | 3.7 | 64 |
| 48 S | 7.75 | 2.1 | 2.6 | 1.7 | 2.1 | 94 |
| 51 S | 6.25 | 2.9 | 2.9 | 3.2 | 3.0 | 108 |
| 53 S | 3.50 | 1.8 | 2.0 | 2.2 | 2.0 | 137 |
| 55 S | 8.25 | 2.2 | 2.4 | 2.4 | 2.3 | 133 |
| 56 S | 5.25 | 2.8 | 2.9 | 3.1 | 2.9 | 131 |
| Subtotal | 108.25 | 49.1 | 52.7 | 53.0 | 51.4 | 2,215 |
| Type mean | 5.70 | 2.6 | 2.8 | 2.8 | 2.7 | 117 |

TABLE 4

SUMMARY OF ANALYSIS OF VARIANCE—SERVICEABILITY RATINGS

| Source | Degrees of Freedom | Sum of Squares | Mean Squares | Variance Ratio | $F_\alpha$ | Level of $\alpha$ | Conclusion |
|---|---|---|---|---|---|---|---|
| P | 2 | 93.265 | 46.632 | 2.328 | 2.39 | 0.10 | NS[1] |
| S | 54 | 996.840 | 18.460 | 60.924 | 1.53 | 0.005 | S[2] |
| G | 2 | 1.613 | 0.806 | 0.094 | 1.41 | 0.25 | NS |
| R | 27 | 230.475 | 8.536 | 28.172 | 1.79 | 0.005 | S |
| P × G | 4 | 8.236 | 2.059 | 1.211 | 1.35 | 0.25 | NS |
| P × R | 54 | 91.780 | 1.700 | 5.611 | 1.53 | 0.005 | S |
| S × G | 108 | 31.604 | 0.293 | 0.967 | 1.08 | 0.25 | NS |
| S × R | 1,457 | 480.619 | 0.303 | | | | |
| Total | 1,708 | 1,934.432 | | | | | |

[1]NS = non-significant.
[2]S = significant.

sections for each pavement type, three overlay pavement sections (sections 2, 8, and 15) were randomly eliminated. This left an ANOV with an equal number of pavement sections for each of the three pavement types from which exact estimates of the components of variance could be obtained.

Table 4 gives the results of the ANOV. The model used was

$$Y_{(i)j(k)l} = \mu + P_i + S_{(i)j} + G_k + R_{(k)l} + (PG)_{i,k} + (PR)_{i(k)l} + (SG)_{(i)j,k} + (SR)_{(i)j(k)l} + e_{(i,j,k,l)}$$

in which

$Y_{(i)j(k)l}$ = rating of the $(k)l^{th}$ rater on the $(i)j^{th}$ strip;

- $\mu$ = mean;
- P = pavement type;
- S = pavement section within pavement type;
- G = rating panel type;
- R = rater within rating panel type;
- PG = pavement type-rating panel type interaction;
- PR = pavement type-rater within rating panel type interaction;
- SG = section within pavement type-rating panel type interaction;
- SR = section within pavement type-rater within rating panel type interaction; and
- e = residual error.

Differences between the pavement sections within pavement types, between the raters within panel types, and the pavement type-rater within panel type interaction were significant at the 0.005 level of probability. Differences between the rating panels, the pavement type-rating panel interaction, and the pavement section within pavement type-rating panel interaction were not significant at the 0.25 level of probability; differences between the pavement types were not significant at the 0.10 level of probability.

The finding that raters within a panel type differed significantly supports the common belief that "the opinions of highway users as to how they are being served may vary widely and even differ." The significant pavement type-rater within panel type interaction means that the differences between the raters within a panel type differed over the three pavement types. As an example: one rater might have tended to rate the rigid pavement sections "higher" than the other raters while he might also have tended to rate the overlay and flexible sections "lower" than the others. Whereas, another rater might have rated the rigid sections "lower" than the other raters while rating the flexible and overlay sections "higher."

It was expected that the pavement sections within a pavement type would differ significantly inasmuch as they were selected to represent all types of pavement conditions varying from very good to very poor. The PSR's of the rigid pavement sections ranged from 1.1 to 4.5; the PSR's of the overlay pavement sections ranged from 2.2 to 4.1; and the PSR's of the flexible pavement sections ranged from 1.5 to 4.1. There was a non-significant difference between the pavement types; that is, the overall means of the three pavement types did not differ significantly. Tables 1, 2, and 3 show the overall means to be 3.1, 3.1, and 2.7, for the rigid, overlay, and flexible pavement types, respectively.

There was a non-significant difference between the rating panels. This is compatible with the statement that the mean highway serviceability ratings of highway authorities were similar to the mean serviceability ratings of the traveling public. The non-significant pavement type-rating panel interaction and section within pavement type-rating panel interaction indicate that the difference between the means of the three panels did not differ significantly over the three pavement types and over the pavement sections within the pavement types at the 0.25 level of probability.

The widely varying ratings of serviceability by individuals is evidenced when one compares individual serviceability ratings and the resulting priority rankings. Raters 1, 2, and 9 of the State Highway panel were selected at random as an example of this variability. They were not the most variable persons in the panels, and neither were they the least variable. Raters 1 and 9 were maintenance engineers; rater 2 was a planning engineer. Some of the individual serviceability ratings and priority rankings of these three persons are presented in Table 5. The priority rankings are based on the individual serviceability ratings; i.e., the lower the serviceability rating, the higher the maintenance or reconstruction priority ranking.

Therefore, if rater 1 were to determine the maintenance program from the nineteen flexible pavement sections included in this study, pavement sections 48, 41, 27, and 37

TABLE 5

COMPARISON OF INDIVIDUAL PRIORITY RANKINGS AND SERVICEABILITY RATINGS OF THREE RATERS—FLEXIBLE PAVEMENT SECTIONS

| Pavement Section | Rater No. 1 | | Rater No. 2 | | Rater No. 9 | |
|---|---|---|---|---|---|---|
| | Rank | Rating | Rank | Rating | Rank | Rating |
| 48 | 1 | 2.1 | 1 | 0.9 | 4 | 1.5 |
| 41 | 1 | 2.1 | 7 | 2.1 | 2 | 1.0 |
| 27 | 3 | 2.2 | 5 | 1.8 | 1 | 0.5 |
| 37 | 4 | 2.5 | 10 | 2.7 | 10 | 2.0 |
| 3 | 5 | 3.2 | 8 | 2.5 | 4 | 1.5 |
| 53 | 6 | 3.3 | 4 | 1.5 | 9 | 1.9 |
| 40 | 7 | 3.5 | 3 | 1.3 | 7 | 1.8 |
| 35 | 7 | 3.5 | 14 | 3.5 | 7 | 1.8 |
| 24 | 7 | 3.5 | 15 | 3.8 | 17 | 4.0 |
| 20 | 10 | 3.8 | 11 | 2.9 | 14 | 3.1 |
| 55 | 11 | 4.0 | 2 | 1.2 | 2 | 1.0 |
| 30 | 12 | 4.1 | 13 | 3.2 | 12 | 3.0 |
| 9 | 13 | 4.2 | 5 | 1.8 | 6 | 1.7 |
| 56 | 14 | 4.3 | 12 | 3.1 | 14 | 3.1 |
| 51 | 14 | 4.3 | 8 | 2.5 | 12 | 3.0 |
| 39 | 16 | 4.4 | 15 | 3.8 | 11 | 2.2 |
| 44 | 17 | 4.8 | 17 | 4.1 | 17 | 4.0 |
| 32 | 18 | 4.9 | 18 | 5.0 | 14 | 3.1 |
| 33 | 18 | 4.9 | 18 | 5.0 | 19 | 4.1 |

TABLE 6

NUMBER OF RATERS REQUIRED TO ESTIMATE THE "TRUE" RATING RATING PANEL EVALUATION METHOD

| Permissible Error | Probability Level | |
|---|---|---|
| | 0.05 | 0.10 |
| 0.3 | 31 | 21 |
| 0.4 | 17 | 12 |
| 0.5 | 11 | 8 |
| 0.6 | 8 | 5 |
| 0.7 | 6 | 4 |
| 0.8 | 4 | 3 |
| 0.9 | 3 | 2 |
| 1.0 | 3 | 2 |

would be the first four sections to be improved and in that order of priority. However, if rater 9 were to determine the maintenance program, pavement sections 27, 41, 55, and 3 or 48 would be the first four sections to be improved. Section 37, which was ranked number 4 by rater 1, would be number 10 on the priority list of rater 9. Rater 2 on the other hand would also rank it number 10 and rank sections 48, 55, 40 and 53 as the first four to be improved.

The individual rating values also vary widely. Section 48 which is ranked number one by rater 1 is given a 2.1 serviceability rating by him and a 0.9 serviceability rating by rater 2. Rater 9 gives it a 1.5 serviceability rating. It is apparent that altogether different priorities and resulting maintenance and reconstruction programs would result if they were determined by different individuals.

The panel evaluation method, however, minimizes the individual variability in serviceability ratings and priority rankings of pavement sections and, if a sufficient number of raters are used, the resulting ratings and priority rankings by several panels of the same size will be virtually the same. The numbers of raters required for a panel which would rate pavements within 0.3 to 1.0 point of the "true" rating at 95 percent and 90 percent probability levels are given in Table 6.

A typical rating study would use one panel. The number of raters in the panel would

TABLE 7

COMPARISON OF SERVICEABILITY RATINGS AND PRIORITY RANKINGS OF THIRTY, TEN, AND THREE MEMBER RATING PANELS AND INDIVIDUALS FLEXIBLE PAVEMENT SECTIONS

| Pavement Section | Serviceability Ratings | | | Priority Rankings | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 30 Raters | 10 Raters | 3 Raters | 30 Raters | 10 Raters | 3 Raters | No. 1 | No. 2 | No. 9 |
| 27 | 1.5 | 1.3 | 1.5 | 1 | 1 | 1 | 3 | 5 | 1 |
| 41 | 2.0 | 1.6 | 1.7 | 2 | 2 | 3 | 1 | 7 | 2 |
| 53 | 2.0 | 1.8 | 2.2 | 2 | 3 | 5 | 6 | 4 | 9 |
| 48 | 2.1 | 2.1 | 1.5 | 4 | 4 | 1 | 1 | 1 | 4 |
| 37 | 2.2 | 2.1 | 2.4 | 5 | 4 | 7 | 4 | 10 | 10 |
| 3 | 2.2 | 2.1 | 2.4 | 5 | 4 | 7 | 5 | 8 | 4 |
| 55 | 2.3 | 2.2 | 2.1 | 7 | 7 | 4 | 11 | 2 | 2 |
| 9 | 2.5 | 2.5 | 2.6 | 8 | 9 | 9 | 13 | 5 | 6 |
| 40 | 2.6 | 2.3 | 2.2 | 9 | 8 | 5 | 7 | 3 | 7 |
| 30 | 2.7 | 2.7 | 3.4 | 10 | 10 | 13 | 12 | 13 | 12 |
| 20 | 2.9 | 2.7 | 3.3 | 11 | 10 | 11 | 10 | 11 | 14 |
| 56 | 2.9 | 2.8 | 3.5 | 11 | 13 | 14 | 14 | 12 | 14 |
| 24 | 2.9 | 2.8 | 3.8 | 11 | 13 | 16 | 7 | 15 | 17 |
| 35 | 2.9 | 2.7 | 2.9 | 11 | 10 | 10 | 7 | 14 | 7 |
| 51 | 3.0 | 2.9 | 3.3 | 15 | 15 | 11 | 14 | 8 | 12 |
| 39 | 3.2 | 3.2 | 3.5 | 16 | 16 | 14 | 16 | 15 | 11 |
| 32 | 3.7 | 3.5 | 4.3 | 17 | 17 | 17 | 18 | 18 | 14 |
| 44 | 3.7 | 3.7 | 4.3 | 17 | 18 | 17 | 17 | 17 | 17 |
| 33 | 4.1 | 4.1 | 4.7 | 19 | 19 | 19 | 18 | 18 | 19 |

depend on the accuracy and level of probability desired. That is, if it were desired that the serviceability rating of the pavement sections be within 0. 5 of the "true" ratings of the sections 95 percent of the time, 11 raters would be required for the panel. If the pavement ratings needed to be within 0. 8 of the "true" rating 90 percent of the time, only three raters would be required.

As noted previously, there was a difference between the ratings and resulting rankings of raters 1, 2, and 9 of the State Highway panel. If the ratings of these three men were averaged, Table 6 indicates that the chances are 19 out of 20 that the mean serviceability ratings of the three men would be within 0. 9 point of the "true" ratings, and nine out of ten that the mean serviceability ratings would be within 0. 8 point of the "true" ratings. Moreover, if mean serviceability ratings of all ten State Highway panel raters were used, this table states that the chances are about 19 out of 20 that the mean serviceability ratings would be within 0. 5 point of the "true" ratings.

TABLE 8

SUMMARY OF RATER CHARACTERISTICS

| Rater | Range Difference | Mean of Ratings | Sum Difference | Sum Dif. Rank | Standard Deviation | St. Dev. Rank |
|---|---|---|---|---|---|---|
| 1 | 2.8 | 3.85 | +50.1 | 1 | 0.438 | 21 |
| 2 | 4.6 | 2.78 | -13.8 | 20 | 0.437 | 20 |
| 3 | 3.5 | 3.44 | +25.7 | 6 | 0.445 | 23 |
| 4 | 2.9 | 2.60 | -24.6 | 29 | 0.358 | 11 |
| 5 | 3.5 | 2.83 | -10.5 | 18 | 0.365 | 12 |
| 6 | 3.9 | 3.04 | + 1.8 | 12 | 0.336 | 9 |
| 7 | 3.3 | 2.85 | - 9.8 | 17 | 0.479 | 26 |
| 8 | 4.8 | 3.63 | + 3.71 | 2 | 0.520 | 28 |
| 9 | 4.6 | 2.66 | -21.0 | 26 | 0.464 | 24 |
| 10 | 3.7 | 2.28 | -44.2 | 30 | 0.412 | 17 |
| Panel mean | 3.76 | 2.996 | | | 0.4254 | |
| 11 | 3.8 | 3.16 | + 9.0 | 11 | 0.319 | 8 |
| 12 | 4.7 | 2.75 | -15.3 | 22 | 0.440 | 22 |
| 13 | 3.6 | 2.66 | -21.4 | 27 | 0.348 | 10 |
| 14 | 3.6 | 2.73 | -17.1 | 25 | 0.297 | 5 |
| 15 | 3.6 | 2.90 | - 6.8 | 15 | 0.245 | 1 |
| 16 | 4.0 | 3.24 | +13.9 | 9 | 0.272 | 4 |
| 17 | 4.0 | 3.28 | +16.3 | 8 | 0.265 | 3 |
| 18 | 4.1 | 2.82 | -11.7 | 19 | 0.302 | 7 |
| 19 | 4.1 | 3.41 | +24.2 | 7 | 0.475 | 25 |
| 20 | 3.6 | 3.56 | +32.6 | 3 | 0.395 | 16 |
| Panel mean | 3.91 | 3.051 | | | 0.3358 | |
| 21 | 3.8 | 2.62 | -23.3 | 28 | 0.376 | 13 |
| 22 | 4.6 | 3.23 | +13.1 | 10 | 0.298 | 6 |
| 23 | 4.0 | 3.55 | +32.3 | 4 | 0.504 | 27 |
| 24 | 4.0 | 2.76 | -15.3 | 22 | 0.389 | 15 |
| 25 | 3.2 | 2.92 | - 5.7 | 14 | 0.428 | 19 |
| 26 | 4.8 | 3.47 | +27.7 | 5 | 0.558 | 29 |
| 27 | 5.0 | 2.73 | -17.0 | 24 | 0.609 | 30 |
| 28 | 3.5 | 2.85 | - 9.7 | 16 | 0.379 | 14 |
| 29 | 4.5 | 2.77 | -14.7 | 21 | 0.427 | 18 |
| 30 | 3.8 | 2.96 | - 3.2 | 13 | 0.255 | 2 |
| Panel mean | 4.12 | 2.986 | | | 0.4223 | |
| Grand mean | 3.93 | 3.01 | | | 0.3945 | |

The mean ratings of raters 1, 2 and 9, the State Highway panel ratings, and the "true" ratings are presented in Table 7 for the flexible pavement sections. The resulting priority rankings are also presented for these three groups of persons and for each of the three raters. The individual ratings for raters 1, 2, and 9 may be found for these same pavements in Table 5. The mean of the 30 individual serviceability ratings (all 30 members of the 3 panels) was assumed to be the "true" rating of a section.

Of the 60 State Highway panel serviceability ratings not one deviated as much as 0.5 from the "true" rating and only two deviated as much as 0.4 point from the "true" rating. Of the 60 mean ratings obtained from the ratings made by the three subject raters, only one deviated 0.8 from the "true" and one deviated 0.9 from the "true." On the other hand, of 60 ratings made by rater 1, 23 deviated 1.0 point or greater from the "true," whereas 17 of those made by rater 2 and 16 of the ones made by rater 9 deviated 1.0 or greater from the "true."

The Highway panel priority ranking of all pavement sections is quite similar to the priority ranking as determined by all 30 raters (Table 7 indicates this for the 19 flexible sections). The three-rater panel (raters 1, 2, and 9) priority ranking was in fair agreement, but individual priority rankings were generally in poor agreement.

It is evident that the panel method of rating, even small panels of three or more persons, is superior to a method which uses individual ratings, as the "accuracy" of rating and priority ranking is appreciably improved.

Although there was agreement by the panels of highway authorities and laymen on the serviceability rating of a pavement, there was some variation of opinion as to the acceptable level of pavement condition. The State Highway panel had the highest standards for acceptability of pavement sections and the lay panel had the lowest standards; in other words, the lay persons as a group did not feel a pavement had to be in as good a condition to be acceptable as did the highway authorities.

It was therefore arbitrarily assumed for this study that if 70 percent of the 30 raters accepted a section, the section would be considered "acceptable" (i.e., the section was satisfactory as it was, and no reconstruction was required to bring it to higher standards at that time). If 50 percent of the 30 raters did not accept the condition of a section, the section was declared "unacceptable" (i.e., improvement was required at an early date). Pavement sections between these 50 and 70 percent limits were classified as "doubtful" relative to acceptability, but at least the condition of these pavement sections was not as poor as those classified as "unacceptable."

Using the above-discussed criteria, a present serviceability rating of 2.5 or higher was found to be acceptable for primary highways and a rating of 2.0 or less, unacceptable. For secondary highways, a rating of 2.0 or greater was acceptable and a rating less than 1.5 was unacceptable. Ratings between those listed were in a zone of doubt as to acceptability.

## Rater Characteristics

Various rater characteristics as evidenced by the ratings such as range difference, sum difference, standard deviation and respective ranking orders, were also summarized and analyzed.

The range difference indicates the amount of the rating scale used by a rater. It is interesting to note that only one rater out of the 30 used the entire rating scale.

The sum difference is the difference of the sum of a rater's ratings from the sum of the 60 "true" ratings (PSR's). A positive sum difference indicates a higher than "true" sum of ratings and a tendency of the rater to rate sections "higher" than the "true" value. A negative sum difference indicates a tendency of the rater to rate the sections "lower" than the "true" value. All 30 raters were ranked from high to low according to the sum differences, thus, the rater ranked number one by this measure was the "highest" rater and the rater ranked number 30 was the "lowest" rater. Table 8 lists these values for the 30 raters of this study with the raters in the State Highway panel listed as numbers 1-10, the Purdue panel 11-20, and the lay panel 21-30. No concentration of "high" or "low" raters occurred in any one of the panels.

The standard deviation of the ratings is a measure of the variability of an individual's ratings and it is an indication of the rater's consistency. Thus, the rater with the lowest standard deviation was the most consistent rater. Each of the 30 raters was ranked as to his consistency to the "true" ratings, and this information is also given in Table 8.

It is interesting to note that seven of the Purdue panel members ranked in the top ten according to consistency but that this concentration of consistency did not result in significantly different panel ratings for the pavement sections. The consistency of these seven raters was offset by the three remaining raters who ranked 16th, 22nd, and 25th in this characteristic.

Two of the laymen were in the top ten for consistency with the three women raters ranked 19th, 29th, and 30th. The State Highway panel had only one of its members in the top ten for consistency.

## Correlation of Serviceability Ratings and Roughness Indexes

Roughness measurements were made on each section of pavement in the study using the standard BPR roughometer owned by the Indiana State Highway Commission. The average values of these readings in inches per mile for each entire pavement section are given in Tables 1, 2 and 3 and were correlated by regression analysis with the present serviceability ratings as determined by all 30 raters.

Scatter-diagrams of roughness values and serviceability ratings were plotted for each pavement type (Figs. 3, 4, and 5). In Figure 3 (rigid pavements) the line shown is the linear regression line which best fits the data and the equation of the line is given. Here y (the present serviceability index) equals 5. 90 - 0. 0241 x (the roughness index). Note that for rigid pavements an excellent correlation exists.

Figure 4 shows the plot and resulting linear regression line for overlay pavements and Figure 5 shows similar data for flexible pavements. The correlation is not as good for either the overlay or flexible pavements as it is for rigid pavements.

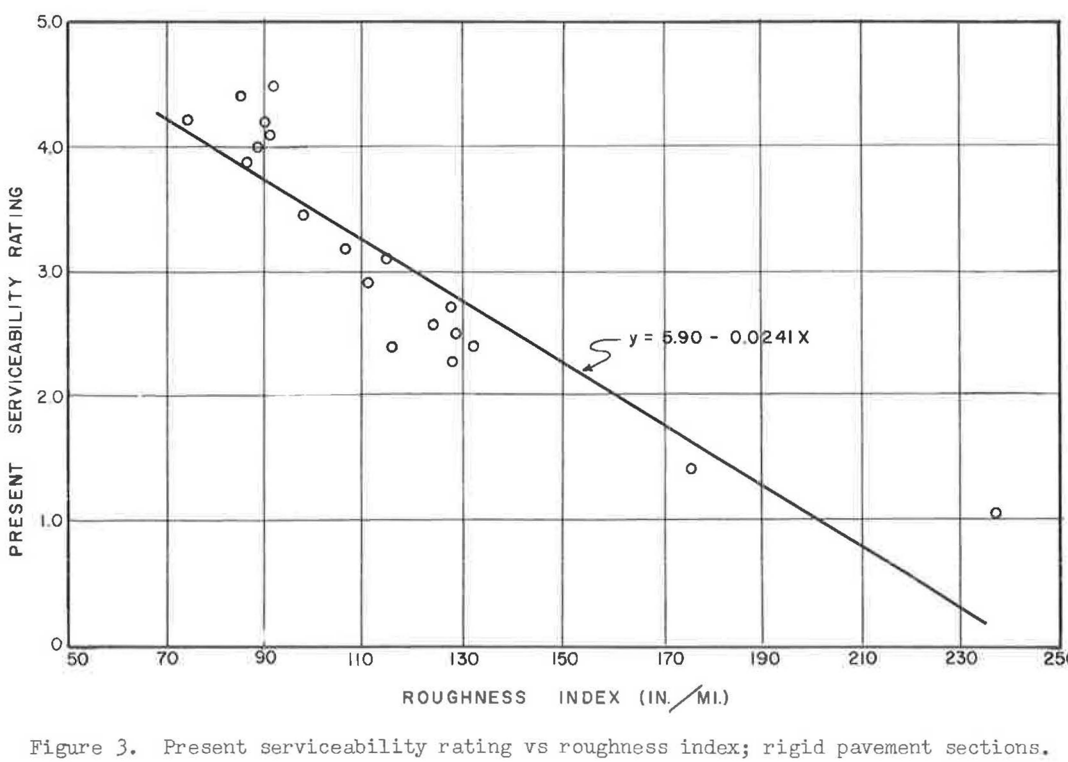



Figure 3. Present serviceability rating vs roughness index; rigid pavement sections.

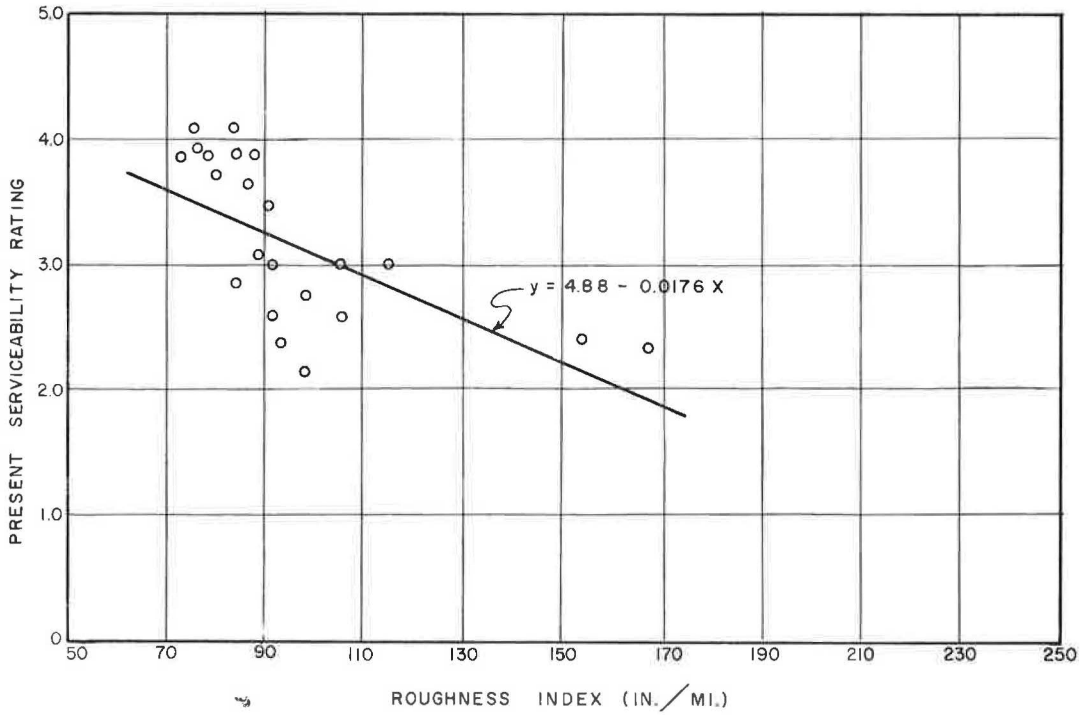



Figure 4. Present serviceability rating vs roughness index; overlay pavement sections.

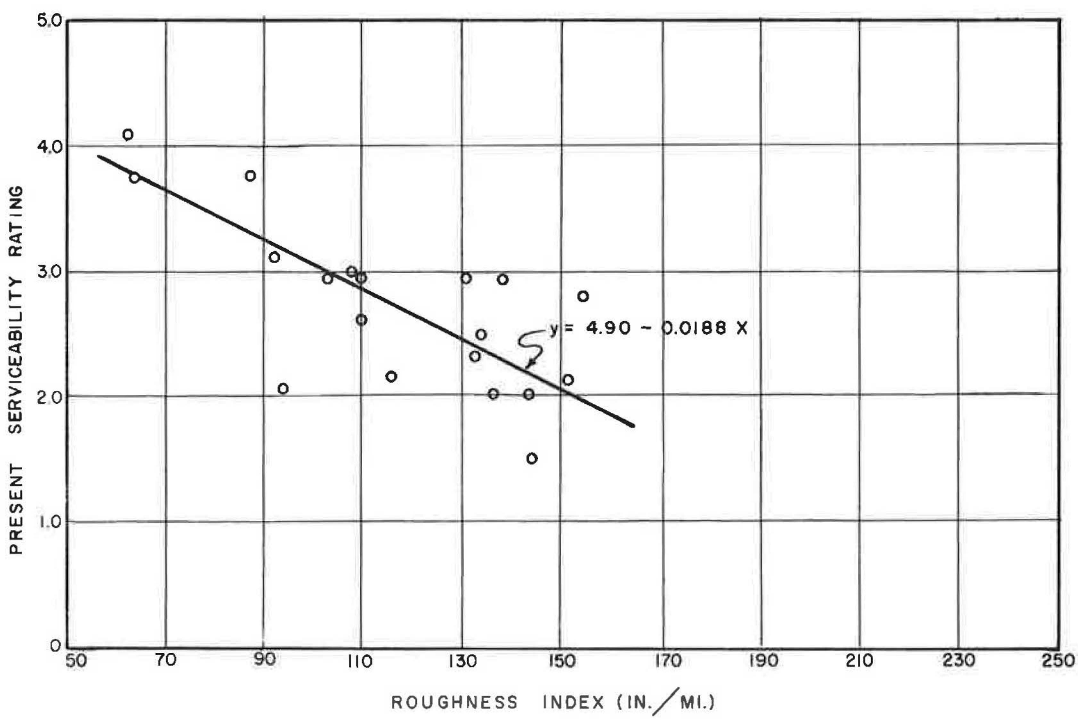



Figure 5. Present serviceability rating vs roughness index; flexible pavement sections.

TABLE 9

CORRELATION COEFFICIENTS AND SQUARED CORRELATION COEFFICIENTS OF PRESENT SERVICEABILITY RATINGS WITH ROUGHNESS INDEXES

| Pavement Type | r | | $r^2$ | |
|---|---|---|---|---|
| | Linear | Exponential | Linear | Exponential |
| Rigid | -0.90 | -0.98 | 0.82 | 0.96 |
| Overlay | -0.65 | -0.72 | 0.42 | 0.52 |
| Flexible | -0.81 | -0.71 | 0.66 | 0.51 |

These scatter-diagrams indicated that an exponential curve might be a better fitting curve than a straight line. The exponential curve $Y = aX^b$ was therefore fitted to the data of each pavement type. The least squares method of regression was used and the following equations resulted:

For the rigid pavement sections:

$$\log Y = 3.2457 - 1.3559 \log X$$

For the overlay pavement sections:

$$\log Y = 1.8874 - 0.7060 \log X$$

For the flexible pavement sections:

$$\log Y = 1.7827 - 0.6640 \log X$$

in which Y was the PSI (present serviceability index, which is an estimate of the present serviceability rating rating) and X was the roughness index.

The resulting equations provided a slightly better fitting curve for the rigid and overlay sections but a poorer fitting curve for the flexible sections. Correlation coefficients, r, and squared correlation coefficients, $r^2$, were calculated for the three pavement types for the linear and exponential cases. The results are summarized in Table 9.

The correlation coefficient, r, indicates the amount of relationship between the serviceability ratings and roughness values. The squared correlation coefficient, $r^2$, is the amount of the variation of the serviceability ratings that may be explained by the roughness values. The negative correlation coefficients indicate a negative association of the variables; that is, as the roughness values increased, the serviceability rating values decreased.

The results clearly indicate the presence of a high correlation between the serviceability ratings and the roughometer values for the rigid sections. Most (82 and 96 percent) of the variation in the ratings may be explained for rigid pavements as dependent on the roughness value. There is, however, only a fair degree of correlation between the ratings and the roughometer values for the overlay and the flexible sections. Roughometer values account for only about 50 percent of the variation in the serviceability ratings of these two pavement types. The other half of the variation in the ratings for these sections, therefore, must be due to other factors which are not evaluated by the roughometer.

## SUMMARY OF RESULTS

If one assumes that the present serviceability rating (PSR) is a good measure of the adequacy of a pavement and further assumes that the best judge of the present adequacy of a pavement is the judgment of the traveling public, serviceability ratings obtained by a large panel of motorists would be an excellent measure of the present adequacy of a highway pavement.

Two methods of determining present serviceability ratings have been presented. One method made use of a rating panel—the number of raters required in the rating panel being dependent on the "accuracy" required for the serviceability ratings. Inasmuch as there were found to be non-significant panel differences, it was concluded that the amount of rater experience and knowledge in the highway field is not of importance in the selection of raters.

The second method used measurements obtained by a roughometer as the independent variable in regression equations to obtain present serviceability indexes (estimates of the present serviceability ratings). When compared to serviceability ratings obtained by a large rating panel, the indexes obtained by the use of roughness measurements were only fair approximations for overlay and flexible pavement sections but were almost exactly the same for rigid pavements.

Because both the roughometer and the panel rating methods provided excellent serviceability ratings for rigid pavement sections, a cost comparison of the two methods was made using the 19 rigid pavement sections in this study as the pavements to be rated. The resulting analysis indicated that a seven-member rating panel would cost only slightly more than the roughometer method. Such a seven-member rating panel would predict mean serviceability ratings that would be within 0.6 point of the "true" ratings 19 out of 20 times. If the accuracy required in the ratings had been such that only six persons or less were necessary, the more economical method in this case would have been the rating panel method.

The decision of which method to use in any case will depend on the use to be made of the results. If the results are to be used primarily for priority determination in program planning, it should be remembered that even a three-member panel produced good results. The method used to determine serviceability ratings for overlay and flexible pavements will also affect the decision as to which method to use for rigid pavements. If the panel method is used for these pavements (and the roughometer method is not good), then it would be efficient to use it also for the rigid pavements.

## CONCLUSIONS

The conclusions made from the results of this study are as follows:

1. The rating panel method of evaluating pavement serviceability is practical; is applicable to rigid, overlay, and flexible pavements; and minimizes the variations and personal bias involved when pavement maintenance and reconstruction priority programs are determined on the basis of the personal knowledge and judgments of individuals.
2. Although pavement serviceability ratings of individuals vary widely, the mean serviceability ratings of panels of individuals do not, and are good estimates of the present serviceability ratings of highway pavement sections.
3. The amount of knowledge and experience in the highway engineering field is not of importance in the selection of members for a rating panel.
4. The roughometer method of evaluating pavement serviceability is objective and simple, but is accurate (i.e., highly correlated with the judgments of the traveling public) only for rigid pavements.
5. The present serviceability index (PSI—an estimate of the present serviceability rating, PSR) of a rigid pavement section can be quite accurately determined from roughometer measurements by the following exponential relationship:

$$\log Y = 3.2457 - 1.3559 \log X$$

in which

X = roughometer output (in./mi), and
Y = present serviceability index (PSI).

A slightly less accurate index can be determined from the following linear relationship:

$$Y = 5.90 - 0.0241 X$$

6. Roughometer measurements are not good predictors of the present serviceability ratings of overlay and flexible pavements.

7. The panel method of obtaining present serviceability ratings for rigid pavements will be more economical than the method utilizing roughometer measurements if the accuracy required of the panel permits the use of a small panel. Cost calculations should be employed to determine the method which is less expensive.

8. Primary highway pavements with PSR's of 2.5 or higher and secondary highway pavements with PSR's of 2.0 or higher are "acceptable" to the traveling public.

9. Primary highway pavements with PSR's of 2.0 or lower and secondary highway pavements with PSR's of 1.5 or lower are "unacceptable" to the traveling public.

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# Use of Pavement Condition Data in Highway Planning and Road Life Studies

GORDON D. GRONBERG, Assistant Deputy Director for Research, Bureau of Public Roads

•BEFORE progressing too far into the discussion of use of pavement condition data in highway planning and road life studies, the term road life should be clarified. These studies more appropriately should be called highway service and investment studies, as they are not only a study of how long various roadway surfaces last before they are resurfaced or reconstructed by also the determination of the annual cost of pavements by surface types, by highway control sections, by routes, and by systems. Also included are such studies as the original cost of highways, roads and streets for grading, surfacing and structures; the investment remaining in each item; and the depreciated investment remaining or the service that has been built in the highway system over the years. In addition, the road life studies include the determination of the service life of the investment in grading, surfacing and structures, and an estimate of highway needs based on the correlation of the forecasted traffic and the depreciated investment remaining. The Bureau is presently working on the annual costs of highways to support different weights and sizes of commercial vehicles. Over the past 15 years the Bureau has encouraged and assisted the States in obtaining detailed information concerning the operation of highways for use in future planning. This work has been accomplished through the promotion of the control section concept and the use of uniform reporting procedures.

There are many more studies included in the road life studies but only two are discussed that tie in directly with the use of pavement condition data: First, work with the States in obtaining detailed information concerning the construction, maintenance and operation and the condition of the highways; and second, the determination of the service lives of the various wearing surfaces for a particular section of highway.

Realizing early in the study of the service lives of pavements, that the results would be only as good as the information on which they were based, the States were continously assisted in improving their reporting procedures. Each State highway department was visited and the use of highway control sections as a basic procedure for keeping adequate cost and operating records of the highway plant was discussed. In 1953 the HRB Committee on Highway Costs prepared Special Report 13, entitled "Know Your Highway Costs." This manual pointed out the limited amount of highway data being obtained by the States for future planning and recommended that such basic information as construction and maintenance costs, traffic, accidents, and the condition of the pavement be kept by segments of the highway called control sections. Of course there were some pioneer States like Michigan that had well-organized pavement condition surveys that dated back to the middle 1920's and California and Oregon that had established control sections in the middle 1930's. Good progress was made on improving the procedures for recording the construction and maintenance costs, some improvement in recording traffic by control sections, but little improvement was made by the States in obtaining information concerning the condition of the pavements. Then the HRB Committee on Pavement Condition Surveys published Special Report 30 in 1957, a manual establishing a uniform procedure for reporting the conditions of the pavements. This was a great help in one of the road life studies which had to do with the reasons for the retirement of a pavement, whether due to obsolescence or structural deterioration. Structural deterioration was further segregated as to whether the reason for retirement was surface failure with the base and subgrade sound; surface and base failure, with the subgrade sound; and surface and base failure resulting from failure of the subgrade.

Because it was impracticable for road life personnel to obtain this retirement information by a field inspection, they reviewed plans of the original construction and subsequent resurfacing and reconstruction operations and relied on the personal opinion of highway department employees who were familiar with the roads. In a few States this information was obtained from pavement condition studies. Since the suggested criteria for HRB Special Report 30 was published in 1957 most of the information for the road life studies as to reason for retirement has been obtained from the pavement evaluation work. This removed much of the personal opinion on which the study had been based and the work of forecasting how long pavements would last and preparing replacement programs for highway needs studies had greater acceptance.

To remove from the realm of speculation the important item in highway transportation economics of the average life of pavements, in the past years three service life studies have been made. Now another one to show the effects of the stepped-up highway program on the average life of pavements is being prepared. To those interested in the development and maintenance of economical highway systems, the importance of reliable average lives of the various types of roadway surfaces need not be emphasized. It is with reliable average lives that the time of needed future construction can be forecast, that the actual annual economic cost of highway transportation can be calculated, and that the true annual cost of various surface types can be determined. Most of you are familiar with the Bureau's road life procedures for determining the average lives of pavements and that they are a study of actual lives realized for particular sections of highway up to the time when the surfaces are reconstructed, resurfaced, or abandoned. From an analysis of these actual lives it is possible by statistical methods (survivor curves) to calculate a general average life for the type of pavement under consideration.

Figure 1 shows the Bureau's curve method of determining the average service lives of pavements. The solid lines show the actual retirement experience for 1934 and 1935 construction and the dashed lines the matching type survivor curve. These type survivor

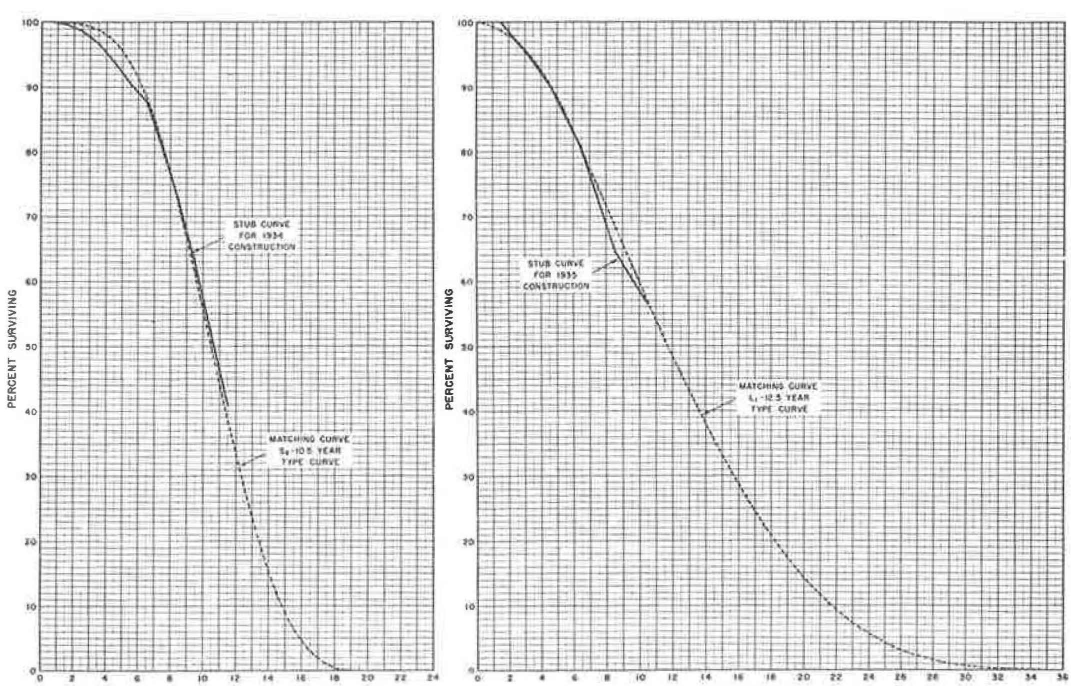



Figure 1. Survivor curves for 1934 and 1935 construction.

curves are from the Iowa Experimental Station Bulletin 125, Retirement of Industrial Properties. These curves were selected because of their good fit. Some of the retirements are mavericks and do not follow a curve at all. Utilizing these matching type survivor curves it is possible to forecast when surfaces will need resurfacing or reconstruction. These service lives are useful in the overall study of retirements and replacement trends but are only averages and do not necessarily apply when a study is confined to an individual section of highway.

Not being satisfied with only average service lives, pilot studies were undertaken to determine the service lives of individual sections of highway. Several State highway departments participated in these studies which were made by a field appraisal of each section of pavement. Even though the State Highway personnel who made these studies brought with them a broad and dependable background of engineering experience, the answers were still based on a considerable amount of judgment. Continuing research of various methods to determine the service lives for individual sections of pavement showed no startling results. However, renewed interest has been generated in this area by the work published on the evaluation of pavement performances and the prediction of future resurfacing operations through the use of the CHLOE profilometer. It is hoped that with the present serviceability index (PSI) taken just before a pavement is resurfaced or reconstructed, related to the age of the pavement and the condition of the pavement obtained from a pavement condition study, to be able to determine the service lives of individual sections of pavement and to forecast the service lives of other similar pavements.

Figure 2 shows a hypothetical case of a portland cement concrete pavement built in 1960 and serviceability ratings taken at 1960, 1964, 1968, 1972, and 1975 and a forecast

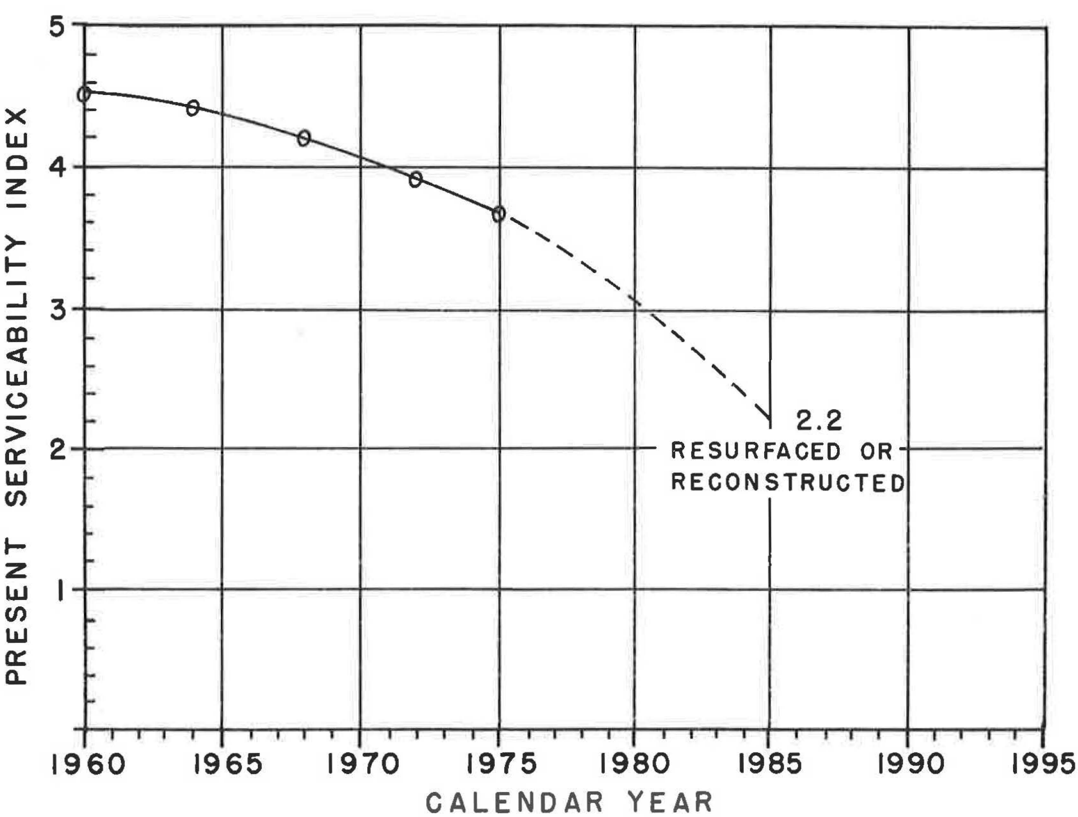



Figure 2. Portland cement concrete—PSI related to years (hypothetical).

to the year 1985. In 1985 it is estimated that the pavement should be resurfaced or reconstructed. Of course the percent of serviceability at which it is indicated that something should be done may differ for each State highway department or by surface types. This type of information has great possibilities in highway needs studies; for example, whether the operation should be included in the first 5 years of a desired construction program or the second 5-year period. This information can easily be revised after each service rating if it does not follow the forecasted trend. In addition there may be a correlation between PSI and the traffic, both amount of daily traffic and the composition of the traffic, which would be helpful. Only time and additional study will tell if progress is being made in the right direction.

It is hoped that this presentation has brought out the importance placed on pavement condition information in the road life studies and the great possibilities of its future use in studies of highway transportation.

# Summary

W. S. HOUSEL, University of Michigan, Ann Arbor

•THIS summary is limited to emphasizing a number of points which seem particularly important, and to suggest some modification of certain other points.

NEED FOR MAKING CONDITION SURVEYS

Highways

Mr. Carey presented three major needs for condition surveys to provide a basis for maintenance planning and construction control and to determine the value of design changes. He states that with the scientific tools now available, these surveys should provide well-defined condition histories based on objective measurements; that the final proving ground for design and the selection or treatment of materials is the highway in actual service; and that construction specifications should include definite limits to control "built-in" roughness.

There are also several ideas suggested by him which the speaker would modify and amplify. He prefaces his discussion with the statement that, "The ability to serve will be called 'condition' here, although we have been calling it 'serviceability'." It is suggested that pavement condition is or should be a completely objective measurement and compilation of physical conditions. Serviceability then could be a purely subjective concept, an attempt to translate condition into a measure of ability to serve the highway user now and in the future.

He continues, "Furthermore, the trend of condition with time and associated loading is pavement performance of behavior." Perhaps this definition is incomplete in a very important sense in that it provides no place for environmental effects quite independent of loading. If a pavement has been adequately designed and built for the loads which it is to carry, it should not suffer structural damage and deterioration under design load applications. Service behavior of many miles of such roads over many years can be cited from the Michigan Pavement Performance Study to show that there has been no significant cumulative change in pavement performance due to load repetition. It is recognized that pavements known to be structurally deficient are quick to reflect the weakness by abnormal deterioration in structural continuity and subsequently in increased roughness. This has been most apparent in the Michigan Pavement Performance Study and these weaknesses and other structural defects show up in the pavement profile with remarkable clarity. On the other hand, it has been equally clear that pavements that are structurally adequate have not escaped the dominating influence of environmental factors. Any concept of pavement performance or method of evaluating performance which omits environment as a controlling variable is less than realistic and will fail to reach its ultimate objective.

Carey is concerned about adverse publicity if there are early signs of pavement requiring heavy maintenance or replacement in the major highway systems now under construction. If this were the case on any substantial percentage of these new highways it would be a serious problem, but the writer is more optimistic, perhaps, and feels confident that the design standards in Michigan will stand the test of time, and data from the Michigan Pavement Performance Study confirm this. On the other hand, there is evidence of results which fall below design expectations within the wide range of physical conditions encountered in practice. In other cases, the failure to meet design standards can be attributed to the difficulty of obtaining high quality performance on the part of all contractors and construction personnel.

It is of particular importance to recognize that data gathered from pavements in actual service indicate that there is much to be learned in protecting pavements from the cumulative deterioration due to environmental influences. In certain respects, these problems are just beginning to be recognized and, if they are to be resolved, pavement design must take them into consideration.

### Airports

Mr. Melville, whose main concern is with airport paving, emphasizes the importance of the structural adequacy of these pavements to carry the heavy loads of present day aircraft. The primary function of condition surveys has been to detect evidence of structural weakness, to check current design procedure, to anticipate future maintenance or strengthening, and to assess the effect on field operation due to possible load limitation. "Riding quality" is not as vital as in highways. It is thus not as serious a problem in airports unless or until the magnitude of surface irregularity gets to the point of affecting the design of landing gear and structural components of the aircraft.

## WHAT CHARACTERISTICS SHOULD BE MEASURED TO DETERMINE PAVEMENT CONDITION

### Flexible Pavements

Mr. Maner lists two major objectives of condition surveys of flexible pavements which to a considerable extent dictate the measurements to be made. These are, first, riding quality or present serviceability, and, second, structural adequacy or ability to provide more permanent serviceability.

He points out that serviceability expressed as a number, either the present serviceability index, PSI, or any other standard of adequacy, is a subjective concept. These measures may vary, depending on the use of the pavement and the user's ideas of what is important in his use of a pavement.

Pavement condition, on the other hand, goes much further than a serviceability index and should include more detailed study that would relate to design and the physical conditions under which the pavement must serve. In other words, a condition survey should show not only that a pavement has reached a certain serviceability level, but why it had reached that level.

### Rigid Pavements

Condition surveys and evaluation of performance may vary in some details when applied to rigid pavements as outlined by Mr. Teske. However, in principle and practical application, the remarks made with regard to flexible pavements apply also to rigid pavements. Structural continuity, for example, may be much easier to measure in terms of a cracking pattern in rigid pavements, but as a measure of structural adequacy it is equally important in both types.

## ANALYSIS AND USES OF CONDITION DATA

Data gathered in pavement condition surveys achieve their real value only when they have been applied to the everyday problems of the design, construction, maintenance, and operation of a highway system.

### Design of Pavements

Mr. Nichols, in discussing the application of pavement condition data to design, makes use of serviceability as defined in the AASHO Road Test. He notes that serviceability alone is not sufficient, and suggests strip photographs to evaluate cracking and patching as a measure of structural adequacy. He feels that a designer must have both criteria if he is to evaluate pavement design.

He closes his discussion with several questions he feels this Committee should answer. Should not equal emphasis be given to measuring present strength as well as present serviceability? Can plate loading tests or pavement deflection observations be used as a measure of structural adequacy? Finally, can the combined data on riding quality, visible defects, and measured strength be combined in a single index of pavement adequacy?

## Maintenance

Some of the applications of pavement condition data to maintenance are quite obvious as, for example, the renewal of riding quality by resurfacing when the roughness has become objectionable. Whether this is maintenance or reconstruction is a moot question. The most important question under maintenance has to do with the need for more than one measure of adequacy. This was pointed out by Mr. Nichols in the example of the bituminous pavement with excessive cracking due to changes in the asphaltic mix requiring sealing long before the defects had been reflected in loss of riding quality. Many examples of this sort could be cited which show the necessity for an independent measure of changes in the structural properties of a pavement. If the great value of timely maintenance is to be realized, this determination must be made, frequently long before the eventual deterioration has reached the point of a measurable loss in riding quality.

Mr. Moe gave a very complete review of the many problems involved in effective maintenance. Emphasis was placed on climatic factors and the fact that timely maintenance is required to combat the deterioration of the pavement due to environment. The importance of systematic inspection and planning of maintenance programs was pointed out. The concluding outline of the elements involved in a well-planned maintenance program includes most of the important factors in pavement condition evaluation.

## Effect of Condition on Vehicle

Professor Quinn points out that while the layman using a highway may evaluate serviceability in terms of his own comfort and convenience, the engineer who deals with pavements and vehicles has more specific problems which require more objective and more precise measures of pavement condition. These problems have to do with the interaction of the pavement and the vehicle, and involve the forces exerted and the reactions developed between the vehicle and the pavement. The problems are further complicated by road-vehicle dynamics with a vehicle possibly even more complex than the pavement structure.

In any event, with regard to the pavement surface it would seem that those working in this field must have an accurate configuration of the surface over which the vehicle moves, which need will be satisfied only by the most precise profile it is reasonably possible to provide. To do less only complicates an already difficult problem to which these investigators are devoting their attention. Professor Quinn has made note of all or most of the mechanical devices now being used as possibilities and would doubtless welcome any that would yield a profile meeting the requirements of accuracy and volume of data to evaluate the effect in the delicate mechanisms which may have to be moved rapidly over present highways.

## Serviceability Ratings of Highway Pavements

Professor Michael has turned his attention largely to those problems which affect the great majority of the riding public. He suggests the subjective concept, based on a panel rating, as the most realistic measure of serviceability. He compares several panels and appears to favor the unprofessional driver whose judgment is unhampered by previous knowledge of highways from design, construction, or maintenance experience.

He compares panel rating with mechanical devices and concludes that with proper controls there is no significant difference in results from these different approaches. However, he does at the end favor the subjective rating on the basis that a mechanical device does not necessarily feel the road as the rider in a vehicle does. In conclusion he indicated the following present serviceability ratings, PSR, as representative of the surveys carried out by the Purdue research project. The public reaction indicated ratings greater than 2.5 on primary roads and 2.0 on secondary as acceptable. The public rated as unacceptable on the same classes of highways present serviceability ratings less than 2.0 and 1.5, respectively.

Planning and Road Life

Mr. Gronberg, who dealt with planning highway improvements and useful life of a pavement, indicated in outline form that road life should be defined in terms of control sections, routes, and systems. Cost data should also consider the investment in various elements of the highway system including highways, roads and streets, further subdivided into grading and drainage, structures, and surfacing.

Construction, maintenance, and operation and the service life of various roadway surfaces all enter into planning and useful life. He suggests that the present serviceability index, PSI, before reconstruction or resurfacing be used as a criterion for pavement life.

## CONCLUSION

In conclusion, it would seem from their review of the elements involved in using pavement condition surveys to evaluate pavement performance, that the panel recognizes the direct applicability of such surveys to the four major functions of a highway department; namely, design, construction, maintenance and operation. While their value in this regard is unanimously accepted, there is still some diversity of opinion on certain important elements of pavement condition surveys on which this moderator has strong opinion.

In the first place, to be of greatest value to all who must use it, it is the writer's opinion that pavement condition should be measured as objectively as possible in quantitative terms divorced from the personal equation involved in subjective ratings. Roughness measurements of one type or another, mechanically recorded and expressed in terms of a numerical index, meet this requirement. The fact that panel ratings properly conducted and analyzed are statistically equivalent as a measure of present serviceability does not destroy the value and practical applicability of a mechanically recorded roughness index.

In the second place, pavement condition surveys fall short of their full potential if they stop at measuring present serviceability and do not provide an answer to the question of how or why a given pavement has reached a specific serviceability level. In this respect, the unique value of a recorded pavement profile lies in providing as accurately as possible the actual configuration of the pavement surface which supplies a remarkably keen tool in the diagnosis of pavement behavior. In addition, such a profile can supply the type of information needed to work out the interrelation between the road and vehicle in the more exacting analysis required to predict the effect of the road on vehicle behavior and vice versa.

# Open Discussion from the Floor

W. N. CAREY, JR., Deputy Executive Director, Highway Research Board—Some of my fellow committee members and others seem to have missed one point about the AASHO Road Test serviceability concept. That is this: no one has made any claim for the present serviceability index as a device by which one can predict future performance. The work "present" is part of the name of this index to circumvent this misunderstanding. Although no one made any direct criticism of the concept, there was criticism by inference in some of the remarks to the effect that the concept falls short because it does not predict future performance. It is not intended to—it never was. Our definition of performance, which you have heard a thousand times, is the "trend" of serviceability with time or with load applications. We do not call performance "serviceability" nor vice versa. It is the trend with time and load applications that we call performance.

We have no argument with those who want to look at things in the small; that is, to find out why one part of a pavement fails. We know that this has to be done. We recognize this requires measurements of the individual components of a structure and clear understanding of drainage and all of these things, but it was never the intention of the Road Test performance concept to do this. The Road Test performance concept was intended to compare designs in the large—over miles, not over one-quarter mile or over one square yard. We think that this can be done rapidly over wide mileages. Please don't accuse us of forgetting those things that influence performance in the small or accuse us of saying that present serviceability, today, by itself, has anything to do with "future" performance. It has to be looked at over a period of time before we can begin to predict future performance.

In my remarks at the beginning of the session I expressed concern that the need for condition surveys in order to predict future maintenance requirements is more acute now than it has been in the past. This is because of the furor that will arise if early maintenance is required on the interstate system. We have made such a splash with this system that the public will be very unhappy if we need maintenance within a few years. I noticed on Gronberg's distribution curve and on Professor Housel's curves a few pavements that have failed, according to their criteria, in 5 to 8 years. I tried to count them on Professor Housel's curves; I counted 9 that had failed in 5 to 8 years. I figured on reading Gronberg's curves that perhaps 20 percent were in bad shape in 5 to 8 years—they had required replacement if I interpret the curves properly. Now if 5 or 10 percent of the mileage on the interstate starts showing severe distress in that short time, that is not to say that we have not designed most of them all right, but visualize 1 mile in 10 as bad and imagine that hue and cry that will result. This is the reason that I think that we must start immediately with continuing condition surveys over all our pavements, particularly the new ones, so that we can spot these cases before they come to the attention of the public and start warning them about it so they will not accuse us of not knowing about it in advance.

LOUIS C. LUNDSTROM, Manager, General Motors Proving Ground, Milford, Mich.—Pavement condition data may be used in the improvement of pavement specifications and in assisting the contractor in an understanding of the quality of work required. Such an application of the data is being developed in connection with the construction of a new test track at the General Motors Proving Ground, Milford, Michigan.

A number of highway sections were first selected in the vicinity of the Proving Ground as samples of surface smoothness that were considered acceptable for the new track. Other sections were chosen to illustrate defects in surfacing that would not be acceptable. Then, subjective ratings, road profiles, and measurements of roughness in inches per mile were taken of these sections. These data and the sample roads were shown to the contractors who will be invited to bid the job.

The specifications will include a detailed description of the required surface smoothness. Good specifications, a clear understanding of the requirements by the contractor, and good inspection on the job should help in providing an excellent surface. If this work continues as planned, additional information will be available a year from now.

G. Y. SEBASTYAN, Head, Engineering Design Section, Air Services, Construction Branch, Canadian Department of Transport—The Canadian Department of Transport carries out a comprehensive pavement condition evaluation survey as part of the Department's overall Pavement Evaluation Procedure.

It may be of interest to describe the principles of this pavement evaluation method.

The Canadian Department of Transport Pavement Evaluation Program consists of appraisal of the following factors: (a) strength of the pavement structure, (b) environmental conditions of the pavement structure, and (c) existing pavement condition.

The strength of the pavement structure is determined by field load testing using repetitive plate load tests (ASTM D1195). In accordance with Department of Transport Procedures, at the time load testing is carried out, the thickness of the various pavement components and the physical properties of the subgrade, subbase, base and wearing surface are determined.

The following factors which influence the environmental conditions of the pavement structure are evaluated: (a) traffic, (b) climatical environment, and (c) drainage environment.

The condition of the pavement structure is evaluated on the basis of the following factors:

1. Structural continuity of the pavement structure is determined using a subjective evaluation by senior engineering personnel. (See typical pavement condition report for flexible and rigid pavements—Figs. 1 and 2.)
2. Roughness of the pavement surface as determined by means of a profilometer which was developed by the British Road Research Laboratories. (Typical results of such surveys are shown in Figs. 3 and 4.)
3. The influence of pavement roughness on an aircraft using a pavement of known roughness is being determined by the instrumentation of a DC-8 jet aircraft. On the basis of this investigation, the following factors will be determined: center of gravity acceleration, acceleration of the fuselage at the nose wheel, lower main gear load, and upper main gear load.
4. Skid resistance of the pavement surface will be determined by a portable type skid resistance measuring device developed by the British Road Research Laboratories.

The data collected are placed on punch cards for reference, correlation and evaluation purposes. A typical pavement evaluation coding form and punch card showing the type of data collected are shown in Figure 5.

Revised 2/5/63

DEPARTMENT OF TRANSPORT

AIR SERVICES CONSTRUCTION BRANCH

# CONDITION REPORT – FLEXIBLE PAVEMENT

AIRPORT ____ SAMPLE ONLY ____

OBSERVER ____ J.D. ____

DATE ____ 16-1-63 ____

EXTRA SHEET OF REMARKS ______ ☐

0: NONE
1: MINOR
2: MODERATE
3: MAJOR
4: SEVERE

10, 9 – VERY GOOD – A
8, 7 – GOOD – B
6, 5 – FAIR – C
4, 3 – POOR – D
2, 1, 0 – VERY POOR – E

| | | 02-20 | 11-29 | TAXI "A" | TAXI "B" | TAXI "C" |
|---|---|---|---|---|---|---|
| CRACK TYPE | HAIR | 1 | 1 | 0 | 1 | 1 |
| CRACK TYPE | LONGITUDINAL | 0 | 1 | 0 | 0 | 1 |
| CRACK TYPE | TRANSVERSE | 0 | 1 | 0 | 0 | 1 |
| CRACK TYPE | CHICKEN WIRE (APPROX. 3") | 0 | 0 | 0 | 1 | 1 |
| CRACK TYPE | ALLIGATOR (APPROX. 6") | 0 | 0 | 0 | 0 | 1 |
| CRACK TYPE | MAP CRACKING (APPROX. 12") | 0 | 0 | 0 | 0 | 0 |
| CRACK TYPE | REFLECTION | 0 | 0 | 0 | 1 | 1 |
| CRACK TYPE | LESS THAN 1/8" | 1 | 1 | 0 | 1 | 1 |
| CRACK TYPE | LESS THAN 1/4" | 0 | 0 | 0 | 1 | 1 |
| CRACK TYPE | GREATER THAN 1/4" | 0 | 0 | 0 | 0 | 1 |
| | STRIPPING | 0 | 0 | 0 | 0 | 1 |
| | RAVELLING | 0 | 1 | 0 | 0 | 1 |
| | RUTTING | 0 | 0 | 0 | 1 | 1 |
| | DEFORMATION | 0 | 1 | 0 | 0 | 0 |
| | DISTORTION | 0 | 0 | 0 | 0 | 0 |
| | SUBGRADE SETTLEMENT | 0 | 1 | 0 | 1 | 1 |
| | SKIN PATCHES | 0 | 1 | 0 | 0 | 1 |
| | DEEP PATCHES | 0 | 0 | 0 | 1 | 1 |
| | LOCALIZED RECONSTRUCTION | 0 | 0 | 0 | 0 | 1 |
| | FROST HEAVE | 0 | 1 | 0 | 0 | 2 |
| | SURFACE ROUGHNESS | 9 | 7 | 8 | 8 | 5 |
| | SURFACE DRAINAGE (PONDING) | 8 | 7 | 8 | 8 | 5 |
| | SUBSURFACE DRAINAGE | 8 | 8 | 8 | 8 | 8 |
| | GENERAL CONDITION | 9 | 7 | 9 | 8 | 5 |
| | GRADED AREA | 9 | 8 | 9 | 9 | 1 |
| | WORK REQUIRED | | ✓ | | ✓ | ✓ |

DRAINAGE REMARKS: SURFACE DRAINAGE (PONDING) 11-29 SURFACE GRADES COULD BE IMPROVED.
" 02-20 - OPEN DITCHES REQUIRE TO BE EXTENDED AT 20 END, OTHERWISE EXCELLENT.
" TAXI "A" - EXCELLENT EXCEPT FOR SLIGHT EROSION OF GRADED AREAS.
" TAXI "B" - VERY SLIGHT PONDING (100'x100'x½") AT JUNCTION OF TAXI "C"
" TAXI "C" - OLDER PAVEMENT SURFACE GRADES POOR
" IN GENERAL - OPEN DITCHES REQUIRE CLEANING & DEEPENING
" SUBGRADE DRAINAGE - VERY GOOD HOWEVER SYSTEM COULD DO WITH A CLEANING. ESPECIALLY THE CATCH BASINS.

GENERAL REMARKS: GRADED AREAS - RATED ON SCALE 1-10. ALL EXCEPT TAXI "C" (OLDER PAVEMENT) ARE IN GOOD ORDER. TAXI "C" GRADED AREAS ARE DEEPLY ERODED AND WHERE SLIGHTLY EMBANKED THE EDGES HAVE BEEN AFFECTED. BOTH GRADED AREAS ARE COVERED WITH SOME LOOSE MATERIAL.

CONTINUES OVER......

Figure 1.

Revised 12/6/63

DEPARTMENT OF TRANSPORT

AIR SERVICES CONSTRUCTION BRANCH

# CONDITION REPORT – RIGID PAVEMENT

AIRPORT _SAMPLE ONLY_

OBSERVER _J. D._

DATE _16-1-63_

EXTRA SHEET OF REMARKS ☐

0: NONE
1: MINOR
2: MODERATE
3: MAJOR
4: SEVERE

10–9 VERY GOOD – A
8–7 GOOD – B
6–5 FAIR – C
4–3 POOR – D
2–1–0 VERY POOR – E

| | | 02 BUTTON | APRON I | APRON II | 20 BUTTON |
|---|---|---|---|---|---|
| CRACKING | CORNER | 0 | 1 | 0 | 0 |
| CRACKING | EDGE | 1 | 0 | 0 | 0 |
| CRACKING | LONGITUDINAL | 0 | 0 | 1 | 0 |
| CRACKING | TRANSVERSE | 2 | 1 | 0 | 0 |
| | SCALING | 0 | 0 | 1 | 0 |
| | SPALLING | 2 | 1 | 0 | 0 |
| | JOINT STEPPING & FAULTING | 1 | 0 | 0 | 0 |
| | CONCRETE DISINTEGRATING | 1 | 0 | 0 | 0 |
| | PUMPING | 0 | 0 | 0 | 0 |
| | LOSS OF JOINT FILLING | 1 | 1 | 1 | 1 |
| | SUBGRADE SETTLEMENT | 0 | 0 | 1 | 0 |
| | FROST HEAVE | 0 | 0 | 0 | 0 |
| | PATCH | 0 | 0 | 1 | 0 |
| | LOCALIZED RECONSTRUCTION | 0 | 0 | 0 | 0 |
| | SURFACE ROUGHNESS | 8 | 8 | 6 | 8 |
| | SURFACE DRAINAGE (PONDING) | 7 | 9 | 8 | 8 |
| | SUBSURFACE DRAINAGE | 8 | 9 | 8 | 8 |
| | GENERAL CONDITION | 8 | 9 | 7 | 9 |
| | JET BLAST OF JOINT FILLER | 2 | 1 | 4 | 0 |
| | WORK REQUIRED | ✓ | ✓ | ✓ | |

DRAINAGE REMARKS:

" SURFACE DRAINAGE (PONDING) 02 BUTTON – SURFACE GRADES NEED TO BE IMPROVED.

" APRON I – EXCELLENT

" APRON II – (OLDER PAVEMENT) SMALL PONDS EXIST AFTER HEAVY RAIN. PONDS FORM IN DEPRESSIONS ALL OVER THE APRON.

" GENERALLY, OPEN DITCHES NEED CLEANING & RE-GRADING

" SUBSURFACE DRAINAGE – EXCELLENT. PIPES SLIGHTLY SILTED

" 20 BUTTON – GRADES POOR

GENERAL REMARKS: JET BLAST OF JOINT FILLER – RATED ON CODE 0-4 & CONCERNS THE AMOUNT OF JOINT FILLING LOSS.

" APRON II IS OLDER PAVEMENT & IS USED BY TWO AIRLINES FOR MAINTENANCE.

CONTINUES OVER......

Figure 2.

# DEPARTMENT OF TRANSPORT

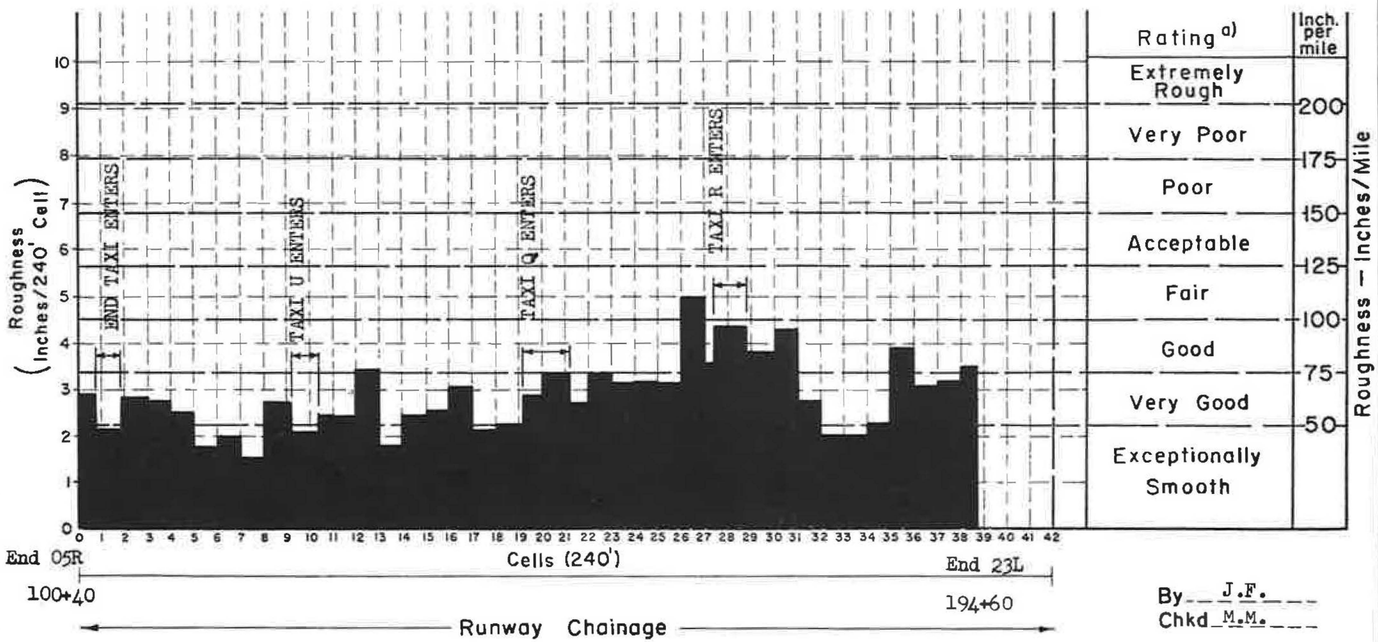
## PROFILOMETER DATA SHEET

### (PAVEMENT ROUGHNESS DISTRIBUTION)

Airport "B" Location Ry 05R-23L Date Tested 14 Aug '62 Station 194+60 - 100+40

Offset 10' 5" of ℄ Pavement Rigid Total Thickness ______ S.G. Type ______

Test Code YZ14/806 Remarks Joints filled only F.I.= 2169'-2702' Footage Indicator 9637 ft.




Sheet ____ of ____

By J.F.

Chkd M.M.

a) University of Michigan

# DEPARTMENT OF TRANSPORT

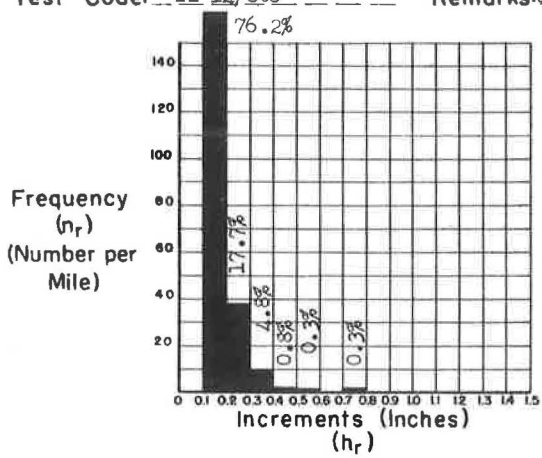
## PROFILOMETER DATA SHEET
(FREQUENCY HISTOGRAM)

Airport "B" Location RY 05R-23L Date Tested 14 Aug '62

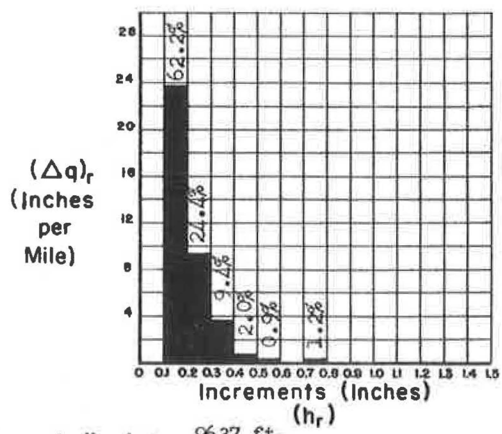
Station 194+60 - 100+40 Offset 10' 5" L of ℄

Pavement Rigid Total Thickness ____ S.G. Type ____

Test Code: YZ 14/806 Remarks: Joints filled F.I.=2169' - 2702'




| $h_r$ | $n'_r$ | $n_r$ | $\bar{h}_r$ | $(\Delta q)_r$ |
|---|---|---|---|---|
| .1 | 284 | 1636 | .145 | 23.72 |
| .2 | 66 | 38.0 | .245 | 9.31 |
| .3 | 18 | 10.4 | .345 | 3.59 |
| .4 | 3 | 1.7 | .445 | 0.76 |
| .5 | 1 | 0.6 | .545 | 0.33 |
| .6 | 0 | 0 | .645 | 0 |
| .7 | 1 | 0.6 | .730 | 0.44 |
| .8 | | | | |
| .9 | | | | |
| 1.0 | | | | |
| 1.1 | | | | |
| 1.2 | | | | |
| 1.3 | | | | |
| 1.4 | | | | |
| 1.5 | | | | |
| Total | | | q = | |




$(\Delta q)_r = n_r \times \bar{h}_r$

$$\left[\begin{array}{l} \bar{h}_r = h_r + 0.045 \\ \bar{h}_{r_{MAX.}} = h_{r_{MAX.}} + 0.030 \end{array}\right]$$

$n'_r$ = Number per test length (footage indicator)

$n_r = n'_r \times f$

$f = \frac{5280}{} = 0.576$

Footage Indicator 9637 ft.
Footage Correction Factor 1/1.05
Corrected Footage 9170 ft.

$\Delta p$ = 109.88 inches

q = Classifier Index 38.2 inches/mile
p = Integrator Index 63.3 inches/mile

By J. F.
Chkd M. M.

Sheet ___ of ___

Figure 4.

NEW ☐
AMENDMENT ☐
DELETION ☐

**DEPARTMENT OF TRANSPORT**
**CONSTRUCTION BRANCH**

# PAVEMENT EVALUATION CODING FORM

| AIRPORT SITE | | | GENERAL AREA | LOCATION | | DATE OF LOAD TEST | | | TYPE TEST | SOIL CLASS | | SUB-BASE TYPE | BASE TYPE | SURFACE TYPE | SUB-GRADE COMPAC. | | SUB-BASE THICKNESS | | BASE THICKNESS | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
| | | | | | | | | | | | | | | | | | | | | |

| PAVEMENT WEARING SURFACE THICKNESS | | | OVERLAY THICKNESS | | | TOTAL FLEX. THICK. | | SUB - GRADE SOIL | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | % PASSING 200 SIEVE | | P. I. | | L. L. | | FIELD MOISTURE CONTENT | | RELATIVE CONSISTENCY | | DRY DENSITY | | |
| 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 |
| | | | | | | | | | | | | | | | | | | | | |

| DEPTH GROUND WATER TABLE | | FROST SUSC. | FREEZING INDEX | | DRAINAGE | LOAD TESTING PLT. DIAM | | LOAD CARRIED IN KIPS | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | ONE REP. 0.2 INCH DEFL. | | | | TEN REPS 0.2 INCH DEFL. | | | | 30 IN. DIAM. 10 REPS: 0.5 IN. DEFL. | | | |
| 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 |
| | | | | | | | | | | | | | | | | | | | |

| RATING (SUMMER) | | | | | RATING (SPRING) | | | | | AGE OF PAVE | | TRAFFIC | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 |
| | | | | | | | | | | | | | | | | | |

| |
|---|
| PUNCHED |
| VERIFIED |
| DATE |

AC-9-4
7-60

DATE ________ ORIGINATOR ________

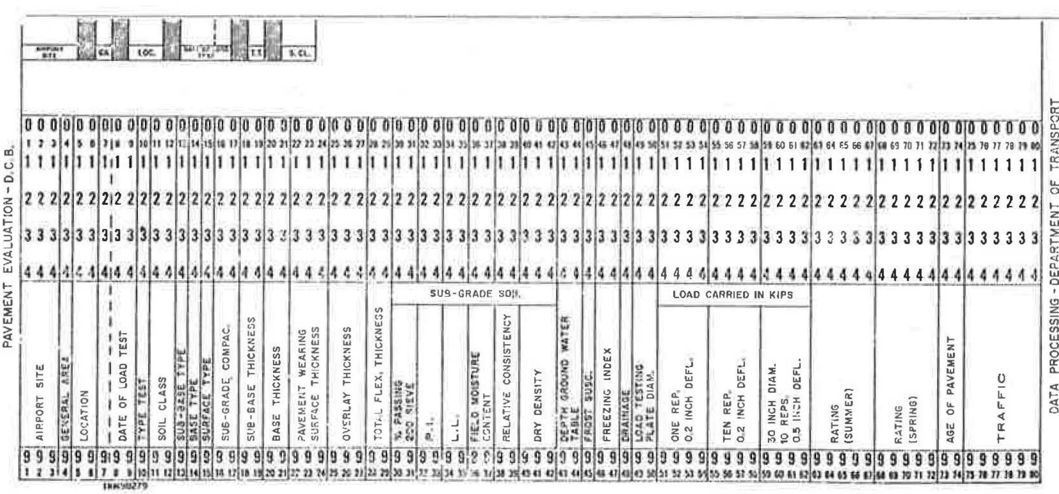



Figure 5.