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Long-Term Pavement Performance:

Proceedings of the SHRP Midcourse Assessment Meeting

April 1991

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Assessment Meeting

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Contents

Foreword vii

Session 1 - LTPP Data Analysis: The GPS Experiments and Data
August 1, 1990

"The GPS Experiments as Implemented"
Gary Elkins, Texas Research and Development Foundation 3

"Biases and Gaps in the Data Base"
Paul Benson, California Department of Transportation 9

"LTPP Traffic Data: What It Really Is"
Mark Hallenbeck, Washington State Transportation Center 23

"Using LTPP to Evaluate Current Design Methods"
Paul Irick, TRDF 41

"International Experiments: A Prime Example"
Boris Hryhorczuk, Manitoba Department of Transportation 53

Session 2 - LTPP Data Analysis: Perspectives on Impacts
August 2, 1990

"The Future of Load Equivalency Factors"
Joe Mahoney, University of Washington 65

"Environmental Factors in Long-Term Performance"
Matthew Witczak, University of Maryland 79

"Impacts on Pavement Design"
Marshall Thompson, University of Illinois 99

"Pavement Rehabilitation: Selection and Design"
Michael Darter, University of Illinois 123

"Pavement Type Selection and Life Cycle Costs"
Michael Markow, Cambridge Systematics, Inc. 139

Session 3 - LTPP Data Analysis: Strategic Objectives
August 2, 1990

"Commentary"
Richard A. Lill, American Trucking Association 155

"Presentation Notes"
Charles Marek, Vulcan Materials, Inc. 157

"Presentation Notes"
Paul Teng, Federal Highway Administration 163

Session 4 - LTPP Data Analysis: Workshop on Approaches
August 2, 1990

"A Proposal to Learn from What We Already Know"
James Brown, Texas Department of Highways and Public Transportation 167

"The SHRP P-202A Work Plan"
Brent Rauhut, Brent Rauhut Engineering (BRE) 169

"The SHRP P-020B Work Plan"
Gilbert Baladi, UMTI 181

"LTPP Data Analysis for UK Roads"
Henry Kerali, University of Birmingham (UK) 197

Session 5 - LTPP: Products and Progress
August 3, 1990

"The Specific Pavement Studies"
Amir Hanna, SHRP 203

"Accessing the Data Base: Policy and Procedures"
Jerome Maddock, Transportation Research Board 209

"Impacts on the AASHTO Guide for Design of Pavement Structures"
William Hadley, Texas Research and Development Foundation 221

"Long-Run Opportunities in LTPP"
Lynne Irwin, Cornell University 227

Foreword

More than four hundred invited representatives of state highway agencies, industry, and research organizations gathered in Denver August 1-3, 1990 to take a close look at SHRP's progress to date, and to suggest adjustments in order to maximize the potential for delivery of immediately useful products when SHRP winds down in 1992.

This document is a collection of the Long-Term Pavement Performance (LTPP) papers and presentations that were made at the SHRP Midcourse Assessment Meeting. While not complete, these proceedings include presentation materials from each of the five technical workshops on pavement performance.

Session I

EXECUTIVE SUMMARY
THE GPS EXPERIMENTS AS IMPLEMENTED

Gary E. Elkins
Texas Research and Development Foundation

The General Pavement Studies (GPS) portion of the SHRP Long Term Pavement Performance program are not a general study of common pavement types used in the United States. GPS includes common classes of pavements that are limited to a carefully selected set of pavement and material types which have potential as cost-effective pavements of the future or have future strategic importance. Selection criteria were established to limit the range of pavements and material types included in the study to those which, based on engineering judgement, were considered to be representative of good pavement practice and in general use. Due to the overall national thrust of these studies, some pavement and material types which have been found to perform satisfactorily were not included into the studies due to the limited area of use and research resource constraints. In addition to pavement and materials criteria, site selection criteria were establish to restrict test sections to a relatively short length which is as uniform as practical.

It has been 4 years since the research plans for GPS were published by the Transportation Research Board in the report "Strategic Highway Research Program, Research Plans" (Brown Book). During the implementation of the GPS studies, changes and refinements were made to the experiments based on lessons learned in the field and through greater feedback from participating highway agencies. The working documents describing these changes have not been widely circulated to the highway research community at large.

During the pre-implementation planning of the Long Term Pavement Performance studies, many optimistic estimates of research progress, implementation of data collection plans and the likely availability of data at the end of the SHRP 5 year effort were made. At this point in the study, a more realistic picture of the amount and character of the data available for the short term (5 year) GPS analysis has emerged. The available data falls short of many initial expectations. Its quality and quantity will directly affect the types of analysis that should be performed and the validity of their results.

This report documents the changes made to the design and structure of the GPS experiments. It provides the final details of project selection criteria and selection methodology. An estimate of the amount and nature of the data available to analyst at the end of the initial SHRP 5 year period is also presented.

Modifications to the GPS Experiments

Although the GPS are generally referred to as experiments, more properly they should be thought of as "unbalanced sampling studies" since the factor levels can not controlled and gaps exist across the factor space. It is for this reason that the orthogonal factorial design layouts of each study are more properly referred to as a sampling templates or sampling designs.

Since the publication of the "Brown Book", the following changes have been made to the sampling designs for each GPS.

GPS-1 ASPHALT CONCRETE (AC) OVER GRANULAR BASE. No change.

GPS-2 ASPHALT CONCRETE PAVEMENT ON BOUND BASE.

- Bound base defined as material improvement due to cementing action of binding agent.
- Allowable base types were expanded and classified into bituminous and non-bituminous.
- Factor level added to include both fine and coarse subgrade.
- Traffic level added as a factor.
- AC stiffness removed as a factor.

GPS-3 JOINTED PLAIN CONCRETE PAVEMENT (JPCP). No change.

GPS-4 JOINTED REINFORCED CONCRETE PAVEMENT (JRCP). No change.

GPS-5 CONTINUOUSLY REINFORCED CONCRETE PAVEMENT (CRCP).

- Dry-No Freeze region added as a factor level.
- Base type removed as a factor and replaced with percent longitudinal steel reinforcement.

GPS-6 ASPHALT CONCRETE OVERLAY OF ASPHALT CONCRETE PAVEMENT

- Study divided into 6A-existing overlay and 6B-planned overlay.
- GPS-6A unchanged. Only one project selected per cell.
- Overlay stiffness removed as a factor from GPS-6B and replaced with pavement condition prior to overlay.

GPS-7 ASPHALT CONCRETE OVERLAY OF CONCRETE PAVEMENT

- CRCP added as a factor level to existing pavement type.
- Study divided into 7A-existing overlay and 7B-planned overlay.
- JRCP pavements in dry no-freeze zones still sought.
- Added CRCP to GPS-7A. Only one project selected per cell.
- Overlay stiffness removed as a factor from GPS-7B and replaced with pavement condition prior to overlay.

GPS-8 BONDED PCC OVERLAY OF JCP AND CRCP. Dropped from GPS due to lack of projects. (Included in SPS program.)

GPS-9 UNBONDED PCC OVERLAY OF PCC.

- Traffic level and subgrade type dropped as factors.
- Accept most projects which fit study title.

The other major change from the initial GPS research plans was shortening the test section length from 1,500 feet to 500 feet in order to maximize test section uniformity. The 500 foot length was selected as the shortest length permitting measurement 250 foot longitudinal profile wavelengths.

Project Selection

Project selection was not a random process. The selected projects were chosen from the nominated projects to provide the best coverage of each studies' inference space. Where multiple projects were nominated for the same cell, the two projects selected for that cell represented the widest spread in the sampling factors possible. For example, if three projects in the same cell had different thicknesses, then the thinnest and thickest projects would be selected. This effectively spreads the inference space to include the sampling factor level extremes. Due to the two levels for most factors, this provides midpoints across continuous factors to evaluate non-linear effects. If the nominated projects had similar levels of sampling factors, then co-variates, such as age, were used to determine which two projects to select. This followed the concept of a well distributed co-variate, where pavement variables not included as a designed sample factor, such as age, shoulder type, etc., are also purposefully distributed to the extent possible in the selection process.

The following priority selection guidelines were used:

1. Select two projects per cell. In some instances three projects were selected.
2. Select projects in the same cell from different states, when possible.
3. Include projects from every state without overloading any one state.
4. Give first priority to projects from the contiguous 48 continental states, followed by "off-shore" states such as Hawaii and Alaska, and use Canadian projects to fill cells where no US projects are available.
5. Distribute continuous factors, such as thickness, traffic rate, and stiffness, across extremes of the available range.
6. Distribute co-variates across extremes of the available range.
7. Include agency special request projects on a case-by-case basis. These projects were generally treated as additional GPS projects and did not count against the total of two projects sought per cell.
8. Accept projects at SPS sites which conform to the GPS requirements as additional projects.

The FHWA funded pre-implementation activities resulted in 2,170 nominated GPS projects by October 1987. Due to multiple projects nominated for the same sample cell, only 650 projects were initially selected. By September 1988, this number was further reduced to 550 as a result of field verification of the initially selected projects and backup projects. This reduction was due to discrepancies between the as-constructed conditions and those indicated on the nomination forms, such as thickness variations, applications of overlays, unplanned maintenance treatments, etc. In october 1988 a renewed recruitment effort was begun to selectively fill the remaining empty cells in each study. By May 1990, 779 project have been accepted into the GPS with 10 more projects pending field verification.

Data Available for the Short Term Analysis

The final details of all of the data collection, processing and storage for the GPS have not been completed at this time. Although specifications for the majority of the data elements have been completed, development work is still progressing on resilient modulus test methods (bound and unbound materials), environmental data, interpretation of distress photographs, scheme for seasonal deflection testing to establish temporal variations, and the processing system and data base for traffic monitoring measurements. Acquisition of the various data elements is progressing at different rates. A large and complex diversity of data sources are being employed in the LTPP data collection effort. The early analyst of short term GPS data must anticipate the use of limited, partial data sets of varying quality. The uniformity and completeness of the LTPP data will improve over time, however, the short term analysis of this data will be most critically constrained by these two aspects. These constraints must be recognized in setting expectations for the results of the short term analysis.

Table 1 presents a summary of a tentative schedule of available data for GPS test sections through December 1991. Although many complete data sets are shown in Table 1 for most items by December 1991, the quality of some of this data will be unknown and its availability to analyst striving to complete work in 1992 may be too late.

Perhaps the most severe data constraint on the short term analysis is traffic data. The short term analysis will have to depend primarily on historical traffic data. It is expected that the bulk of this data will be based on non-site specific measurements and will be highly extrapolated. The variability or confidence associated with these estimates will, in most cases, not be possible to quantify. Very few complete data sets from site specific monitoring measurements on the GPS test sections are expected to be available in time for use in the early analysis. **The lack of accurate-quantified traffic loading statistics will severely constrain the validity of any pavement performance relationships derived from the short term GPS analysis.** In time, when a sufficient quantity of site specific traffic monitoring measurements are available, the historical traffic loading and volume estimates can be evaluated with respect to the measured loads and volumes and adjusted as appropriate.

Conclusion

Significant changes have been made to the GPS design during implementation. Data acquisition activities have not progressed as rapid as initial expectations. The short term analysis of GPS data will be severely constrained by the quantity and quality of available data. The quality and quantity of data will improve over time with the maximum benefits to be derived from mid to long term analysis.

Table 1. Tentative schedule of data availibility for GPS test sections through December 1991.

Module	12/90	12/91	Comment
Environment	◓	●	
Historical Traffic	◓	●	
Existing Structure	●		
Materials Properties	◓	●	
Deflection	●	● ◓	Partial 2nd Round
Profile	●	● ●	2 rounds complete
Surface Distress	●	● ◓	Partial 2nd Round
Friction Data	◓	●	
Traffic Monitoring	◓	●	Some sites will not have one full year of measurements
Maintenance History	◓	●	Past Records Suspect
Rehabilitation History	◓	◓	

◓ Data not available for all sections

● Data available for all sections

BIASES AND GAPS in the GPS Database

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INTRODUCTION

In laboratory experiments, researchers can choose the factors they will control and the levels at which they will study them. If interested in specific factors or combinations of factors, they can design a partial experiment that emphasizes those factors. They can also limit potential sources of bias by calibrating their equipment regularly and selecting their test specimens randomly.

This degree of control was not available to the designers of the General Pavement Studies (GPS) portion of SHRP's Long Term Pavement Performance Program (LTPP). The GPS mandate was to learn from existing pavements. While the designers were able to select the factors they would study, the levels of the factors could only be controlled in very general terms. Since existing pavements were designed from a limited set of standardized procedures, many combinations of these levels were simply not available. The combinations that were available were often distributed unevenly between environmental zones.

The design was further complicated by the logistics of the program. Site nomination was conducted by individual states and site approval and testing by regional contractors. These were necessary procedures for a project of this magnitude, but they had the potential for interjecting bias into the study.

Designers of the GPS had to deal with many deviations from the ideal laboratory environment. It is inevitable that the completed database will contain some effects of the compromises that were made. The preliminary phases of the GPS analysis should explore the extent to which sources of bias and gaps in the database might limit the achievement of the overall GPS objectives.

GAPS IN THE DATABASE

The sampling matrices that were designed for the GPS were an attempt to achieve as large an inference space as possible given SHRP's budget for LTPP. A separate matrix was constructed for each pavement type studied. They were based on the factors first identified in the 1986 SHRP Research Plans (1) and later modified by SHRP through its advisory committee and expert task group structure. For the most part, each factor was studied at two levels: "high" and "low". The resulting 2^n factorial sampling designs comprised all combinations of the design factors. Each combination was designated as a cell in the sampling matrix. As originally planned, each cell would contain two sites from different states and of different ages. Pavement age would be treated as a covariate in the sampling designs.

The sampling matrices formed the basis for an unweighted, stratified sampling plan that would overcome the predominance of standardized designs in the existing pavement population. Had a completely randomized site selection approach been followed, few unusual pavement designs would have been studied and conclusions would have been confined to performance of standard pavements. In stretching the limits of the sampling matrices to include unusual combinations of design and environmental factors, it was expected that some cells would remain unfilled. These unfilled cells comprise what Paul Irick has termed, "factorial gaps" (2). It was hoped that they would occur in a relatively balanced pattern throughout the matrix. Significant deviations from a balanced pattern would give undue influence to test sections in sparsely populated regions of the matrix and reduce resolution of interactions between design and environmental factors.

A measure of the relative balance of the GPS sampling plans was devised by Robin High (3). This measure is given as the ratio of the median expected variance of the best balanced design for a given number of test sections to the median expected variance of the actual sampling pattern achieved, more simply stated as:

$$\text{EFFECTIVENESS} = 100 * \frac{\text{Desired Variance}}{\text{Median Variance Achieved}}$$

The "Effectiveness" measure was used to identify priority cells for the final round of GPS test section recruitment that began with issuance of the June 1988 GPS sampling plan (4). A target level of 85% effectiveness was set for each of the five GPS studies on original pavements.

GPS test sections are nominated by states and then either approved or rejected based on site visits by the regional contractor and SHRP representatives. Approved sections are eventually verified by coring. Verification results may shift the location of a test section within the sampling matrix or eliminate it altogether. Experience to date has proven that most sections are reliably located after the approval stage. Except where noted, the figures and tables presented in this paper are based on the distribution of approved sections on June 30, 1990 (Figure 1). For a given study, the greater the discrepancy between approved and verified sections shown in Figure 1, the greater the potential for a shift in the final distributions.

Table 1 shows the results of the second round recruitment efforts. In the case of GPS-1, a significant number of cells were lost or shifted location. Revision of design parameters and heavy recruitment led to a dramatic expansion of the GPS-2 study. The remaining three GPS studies showed modest gains.

Table 2 gives the average number of sections within each occupied cell for 1988 and 1990. Faced with continued difficulties in recruiting priority cells, SHRP decided to allow cells to contain more than two test sections. This would increase the degrees of freedom of the database and permit the incorporation of attractive candidate sites for cells already filled. However, it also had the potential for further unbalancing the sampling matrices.

There was little change in the average number of test sections per occupied cell between 1988 and 1990. Attrition of sections, lost during verification, and the need to expand into unoccupied cells whenever possible led to an increasing number of single occupant cells. These trends were offset by the increase in the allowable number of test sections per cell.

A reexamination by Texas Research and Development Foundation (TRDF) found that the 1990 sampling matrices had improved design effectiveness over the March 1989 figures (5) for GPS-1 thru 3, but worsened for GPS-4 and 5 (Table 3). For a model of medium complexity, the target value of 85% effectiveness had been achieved for all but GPS-4.

Meanwhile, the portions of the GPS that were focused on overlay pavement performance, GPS-6A/B, 7A/B and 9, were moving along somewhat slower. Additional coordination with other SHRP programs necessitated a longer design period. Obtaining test sections for which overlays were imminent further complicated the process. As a result, gaps in the overlay studies are more extensive than for GPS-1 thru 5. This can be seen in Figure 2, where the percentage of the full factorial experiment (i.e. percent of cells containing at least one section) is given for each GPS study. It is expected that additional recruitment of overlay test sections will be ongoing as part of the proposed 20-year LTPP.

The question of balance in the partial factorials remains an important one. Figure 3 shows the percent of full factorial achieved by each GPS study categorized by environmental zone. There is a sizable imbalance for most of the studies. A model based heavily on pavement performance in one environmental zone that is employed for design of pavements in another zone has significant potential for either over- or underdesign. This is the very problem with existing design methods that SHRP is seeking to alleviate. The analysis of at least some of the GPS data on a zonal basis may be mandated by the distributions shown in Figure 3.

Balance across design variables is another desirable goal for each GPS study to attain. It is no secret that finding thick pavements with low traffic and thin pavements with high traffic is not easy. Figures 5 and 6 show the distribution of percent full factorial achieved for the four combinations of traffic and pavement thickness. Good balance is achieved for thin pavements in GPS-2, 4, 6A and 7A. Assuming these are not heavily grouped in one environmental zone or state, they can be considered well balanced overall. Low traffic on thick pavements (i.e. overdesigned pavements) are consistently underrepresented in all studies. Since more attention will be focused on the performance of the underdesigned pavements, this is not a serious shortcoming.

The "evaluation gap" is the second type of gap identified in Paul Irick's paper. An evaluation gap exists when data is missing for a specific variable in the database. For instance, a resilient modulus test may be missing for a specific section. Sporadic missing data of this sort can be handled using interpolative schemes with little loss to overall efficiency. The real evaluation gap problem for GPS arises out of the staggered availability of the data by data type. If all the data is available except for one key independent variable, the analysis cannot proceed. Preliminary examination of the data can and should be done. For instance, analytical assumptions can be verified, promising model forms identified, and problems with multicolinearity explored. But the GPS objective of verifying existing design procedures and modifying them or developing new ones cannot proceed until large-scale evaluation gaps are filled.

BIAS IN THE DATABASE

Any study of the size and complexity of GPS is bound to contain bias. SHRP was aware of this from the beginning and did all that was possible to minimize the problem. For example, they issued working documents on testing and site selection procedures, performed equipment calibrations, and selected experts with a variety of perspectives. Why were they so concerned about bias? Very simply, if uncontrolled it could lead researchers to develop erroneous conclusions and models.

Every experiment design contains an element of uncertainty.

This is usually signified in the design equation by an error term. The error term is made up of both random and systematic components. As long as the sum of these two components is small compared to the variances of the controlled factors, conclusions can be reached with reasonable confidence. If the random component becomes too large, conclusions cannot be reached. If the systematic component becomes too large, the wrong conclusions can be reached.

Bias is a process which creates systematic error. It can significantly influence the results of an experiment. If it is unplanned and remains hidden, faulty conclusions are possible. It can also be exercised in a planned manner to achieve specific objectives.

Planned sources of bias in the GPS include the sampling matrices themselves, the selection of sites with no overlay history, and restrictions on geometrics. Each of these biases were exercised to achieve necessary and worthwhile objectives. But even well-intentioned bias has the potential to backfire on the researcher. For example, the sampling matrices were governed by our opinions about which design and environmental factors are important and which are not. If we were wrong and overlooked a critical factor, our analysis will suffer. Also, by choosing only older pavements that have not been overlayed, do we run the risk of developing design models that are based on our best constructed projects? And what if, by excluding roadway sections on fill, grade or curves, we are excluding the hardest sections to build and maintain?

Unplanned sources of bias can also lead to equally disturbing questions. The site selection process is a leading candidate for potential bias. At the project level, 50 states may have interpreted the selection criteria 50 different ways. Were there projects that should have been nominated that were not? Did some states participate more heavily than others?

Figures 6 and 7 show the distribution of state participation by centerline miles per GPS site for both flexible and rigid pavements. Clearly, state participation was not even. The preponderance of states with a low ratio of centerline miles to site are the result of SHRP's mandate to get participation by all states. Figures 8 and 9 flag high and low participation by several states.

Uneven participation by the states is only a problem if specific design or maintenance practices vary drastically from state-to-state. A design model heavily influenced by one state with one set of practices and employed in another state with completely different practices could prove unsatisfactory.

Many of these questions can be answered with the proper preliminary analysis of the data. The distributions of individual variables can be checked for skewness, kurtosis and extreme values. The wealth of supplementary data collected for each test section can be explored for associations that were not anticipated by the designers of GPS. Most importantly, detailed residual analyses should be performed on any models that are developed. Residuals are defined as the differences between paired observed and predicted values of the dependent variable (i.e. distress variable). The residuals can be plotted against suspected sources of bias and tested for correlations using nonparametric tests. They can also be plotted against each of the model variables (both dependent and independent) to check for potential linear transforms or non-linearity in the data.

CONCLUSIONS

The existence of biases and gaps in the GPS database is an unavoidable consequence of the nationwide scope of the project and the uniformity of the existing pavement population. The first order of business for analyzing the database is to explore the degree to which these biases and gaps may limit fulfillment of the GPS objectives. This can be accomplished by pursuing the following actions:

1. Limit the inference space in cases where the factorial sampling matrices are hopelessly unbalanced or independent failure mechanisms are suspect. Explore the viability of regional models where appropriate.

2. Combine studies to achieve better balance in cases where the suspected failure mechanisms are the same and the factorials are compatible. Possible candidates for combination are GPS-1 and 2.

3. Review regional operations to identify any potential sources of bias in either testing or site selection procedures. For instance, determine how each region selected the 500 foot test section within a project after all portions of the project not satisfying SHRP criteria were removed from consideration.

4. Examine the distributions of both dependent and independent variables checking for non-normality, bi-modalism and extreme values. Follow-up with a search for causative factors not previously considered but included in the GPS database. For example, a bimodal distribution of a distress pattern might be linked to two specific types of maintenance histories.

5. Conduct a thorough residual analysis as soon as preliminary models are developed. Plot residuals against project age, state, region, month tested and any other variables that might have contributed significant bias to the database.

ACKNOWLEDGEMENTS

The author would like to thank Robin High and Ed Pensock of TRDF staff for their valuable assistance in preparing this paper.

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TABLE 1. GPS RECRUITMENT (1988 to 1990)

Study No.	Cells Gained	Cells Lost	Net Change
1	17 (1)	30	-13
2	46	6	+40
3	12 (12)	8	+4
4	7 (3)	2	+5
5	8 (3)	4	+4

( ) - Priority Cells

TABLE 2. AVERAGE NUMBER OF TEST SECTIONS PER OCCUPIED CELL

Study No.	1888	1990
1	1.77	1.76
2	1.52	1.56
3	1.76	1.68
4	1.88	1.90
5	1.85	1.81

TABLE 3. EFFECTIVENESS ESTIMATES (%) OF GPS DESIGNS

	Model Complexity			
	Medium		High	
Study No.	3/29/89	6/1/90	3/29/89	6/1/90
1	99	99	94	98
2	78	86	77	85
3	79	87	75	79
4	65	58	54	45
5	91	89	77	69

Figure 1.
GPS STATUS (6/30/90)

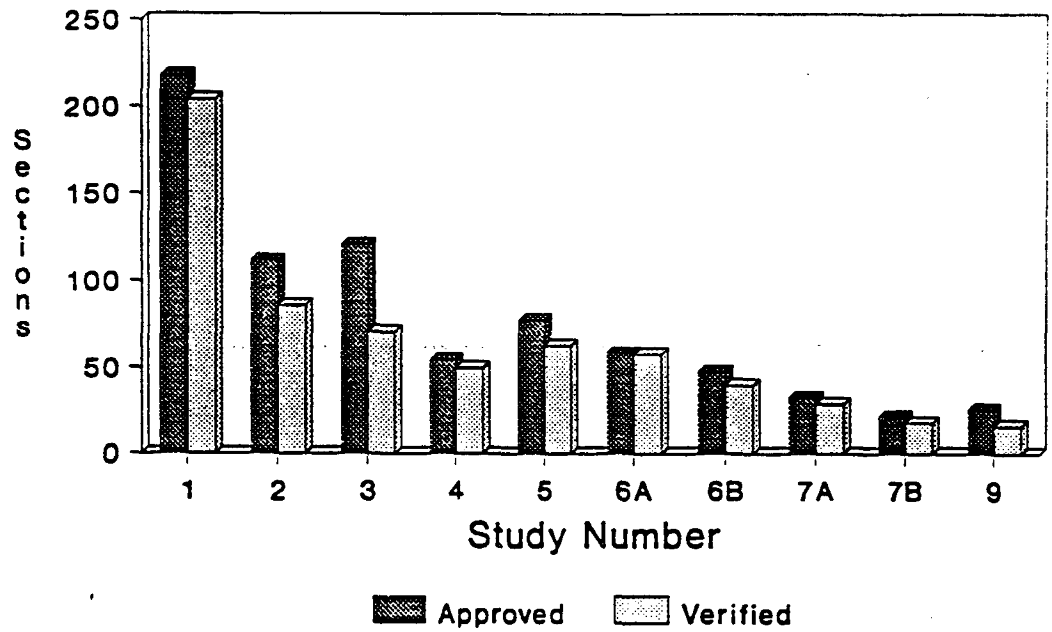


Figure 2.
PERCENT FULL FACTORIAL

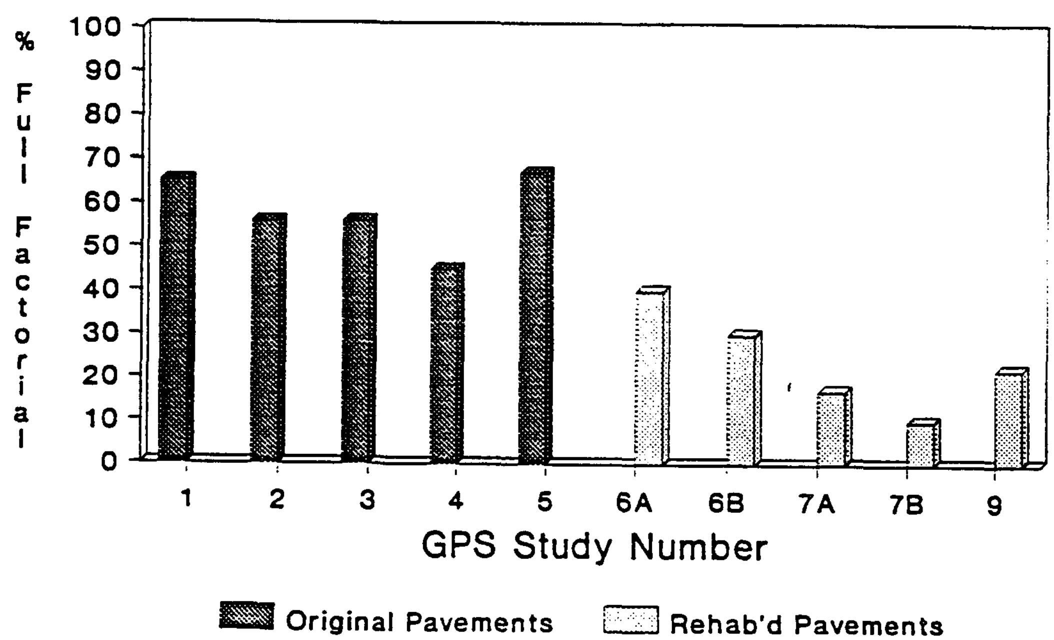


Figure 3.
PERCENT FULL FACTORIAL
BY ENVIRONMENTAL ZONE

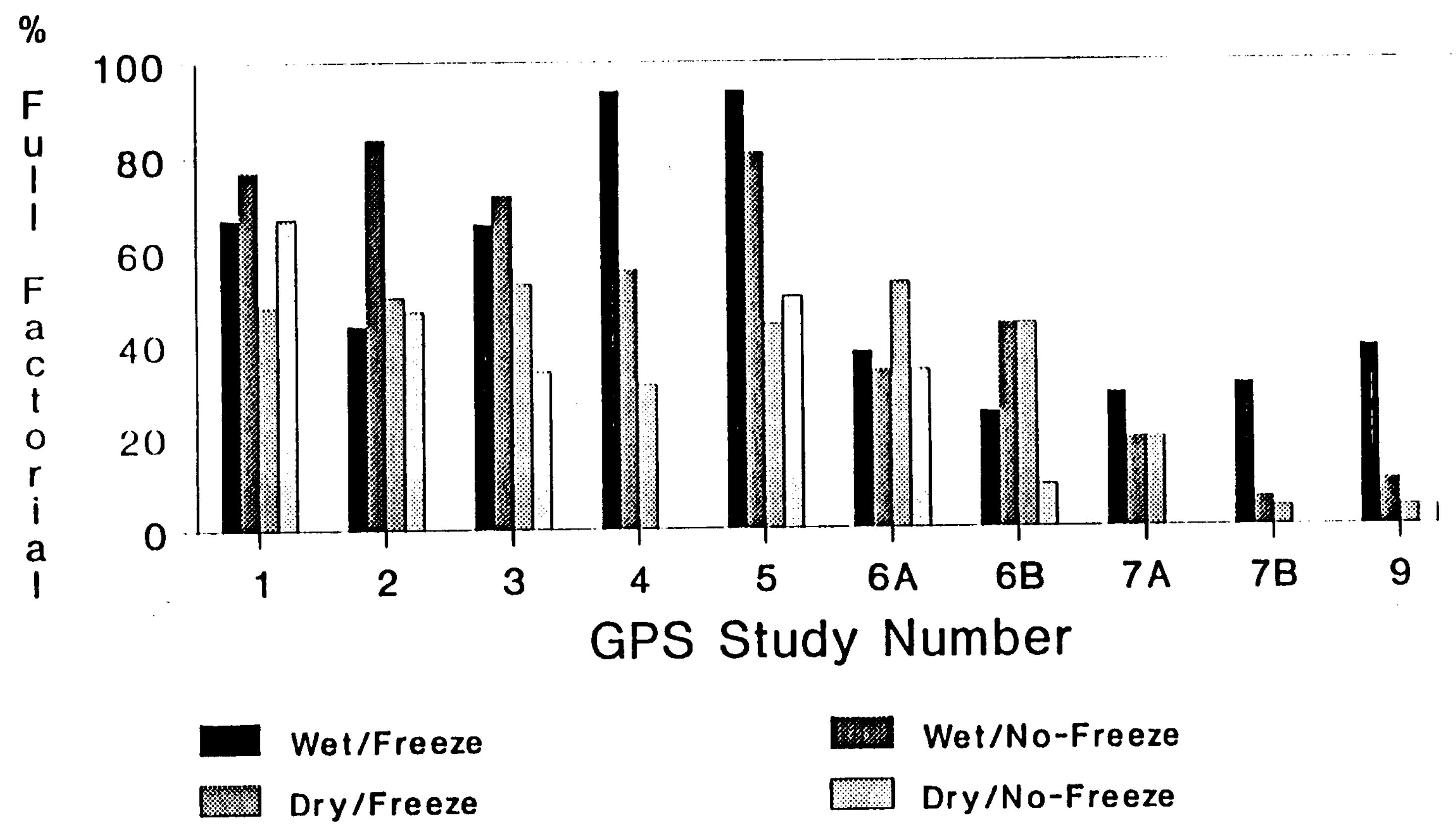


Figure 4.
DISTRIBUTION OF LOW AND HIGH
TRAFFIC FOR THIN PAVEMENTS

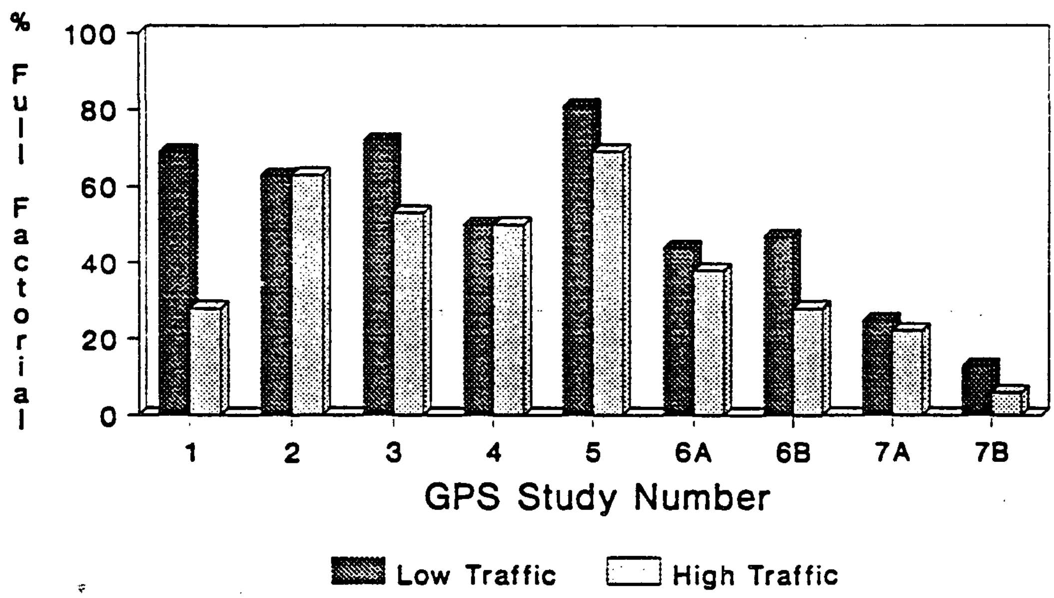


Figure 5.
DISTRIBUTION OF LOW AND HIGH
TRAFFIC FOR THICK PAVEMENTS

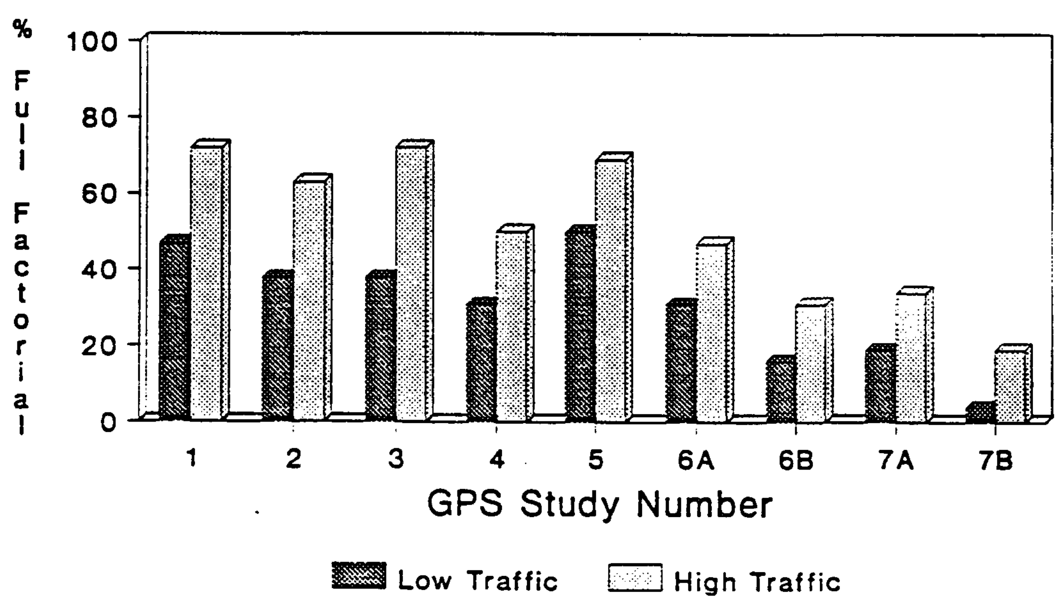


Figure 6.
DISTRIBUTION OF GPS SITES
(Flexible Pavements)

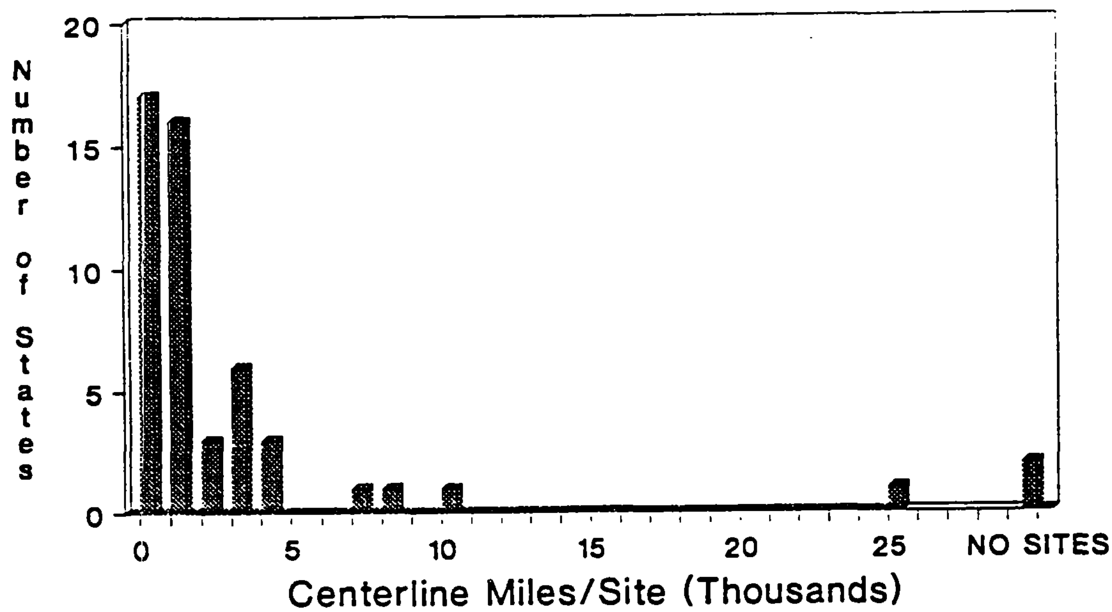


Figure 7.
DISTRIBUTION OF GPS SITES
(Rigid Pavements)

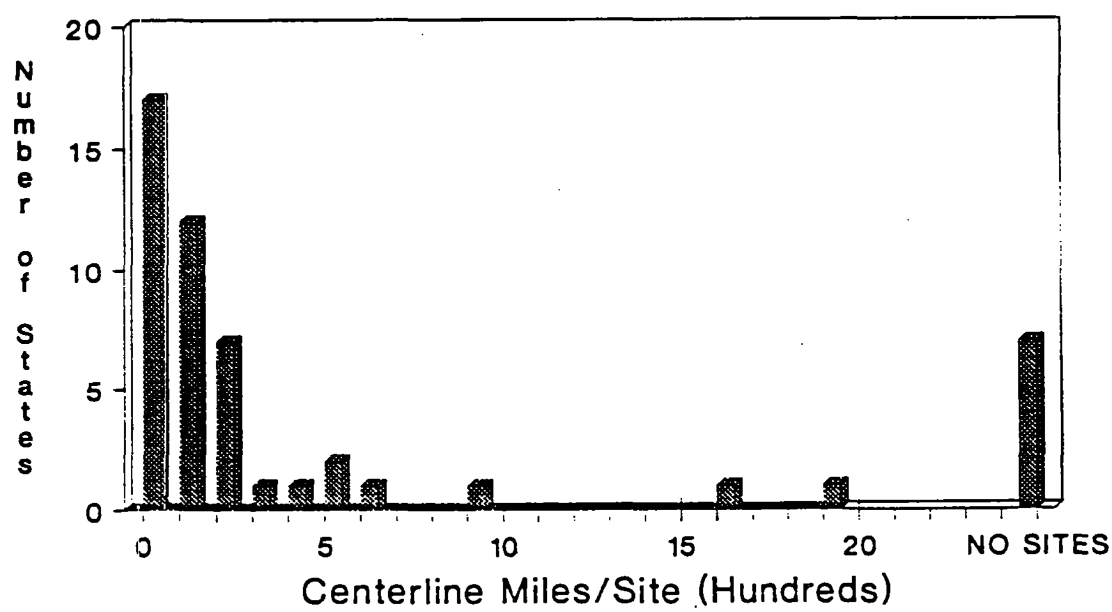


Figure 8.
GPS SITES BY STATE
(Flexible Pavement)

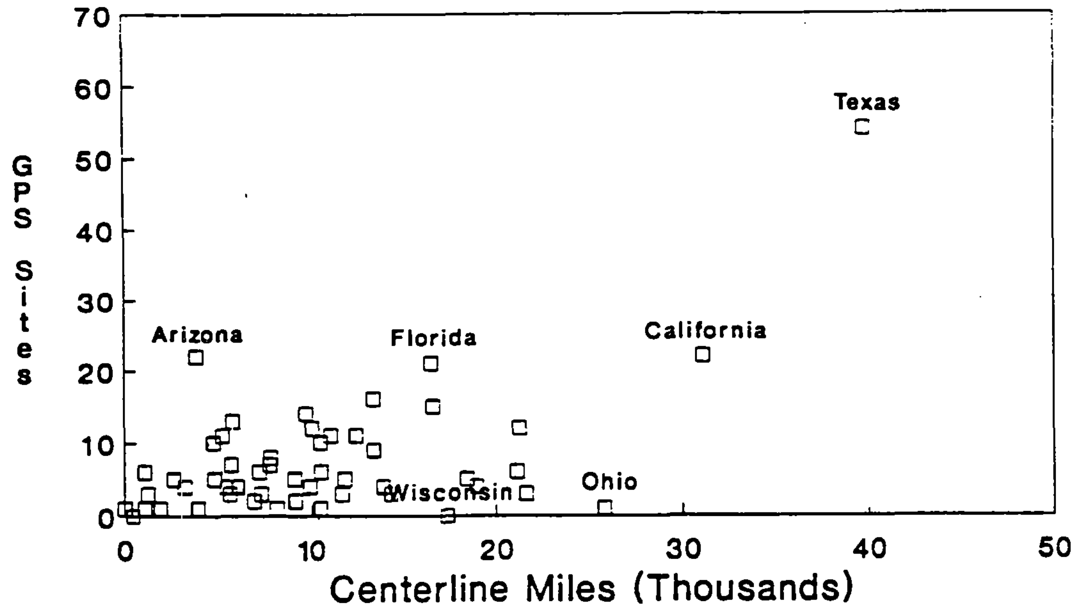
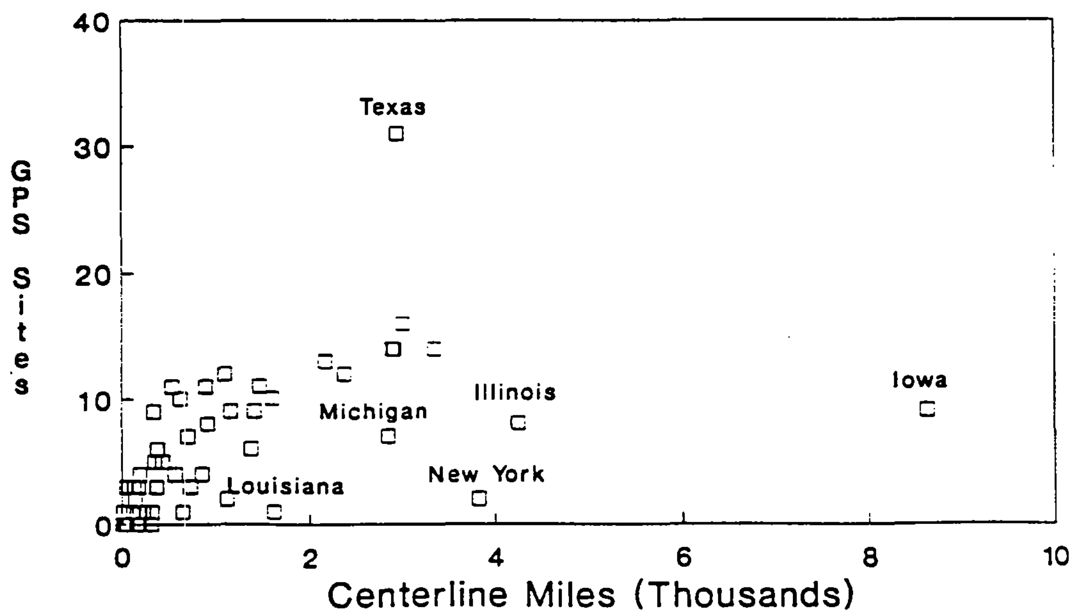


Figure 9.
GPS SITES BY STATE
(Rigid Pavements)



THE SHRP TRAFFIC DATABASE
WHAT IT REALLY IS

By
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Washington State Transportation Center (TRAC)

Presented at the Denver SHRP Meeting
August 1-3 1990

INTRODUCTION

The original SHRP LTPP experiment design assumed that a low cost ($5,000 per lane) weigh-in-motion (WIM) scale would be available to the states and provinces (SHAs) at the beginning of the LTPP experiment. Therefore, early SHRP planners assumed that a low cost WIM device could be permanently located at each SHRP LTPP site to record the axle loadings that crossed the site during the LTPP experiment.

Because the cost of WIM technology did not decrease as quickly as expected, this data collection plan became impractical. Consequently, SHRP formed an expert task group (ETG) to look at alternative methods for collecting, storing, and manipulating the traffic data to be used in the LTPP experiments. The data collection plan developed by this ETG takes into account the lack of knowledge the transportation profession has about the inherent variability of the various traffic parameters (volumes, vehicle classifications, and truck weights), the limitations in available data collection equipment and SHA personnel, the financial realities of collecting these data, and the impacts imprecise traffic data will have on the LTPP research results.

The end result is a flexible plan for traffic data collection that sets minimum levels of data collection for each LTPP site but encourages SHAs to provide more and better data collection where fiscal and physical limitations can be overcome. The basic plan elements are as follows:

- preferred data collection - permanent, year round weigh-in-motion,

- desirable data collection - four week-long, seasonal weigh-in-motion measurements at each study site, supplemented by a permanent, year round vehicle classifier, and
- minimum data collection - at least one year of year round vehicle classification during each five-year SHRP funding period, with four weekend and four weekday weigh-in-motion measurements spread throughout the seasons during that time period.

This flexible plan is beneficial to the SHAs, in that it recognizes the realities of their funding and staffing limitations and allows them to better utilize their scarce resources. At the same time, it provides enough information to SHRP researchers to allow the valid estimation of traffic loadings for the LTPP research experiments. While this flexibility reduces the cost of traffic data collection to the SHAs, it increases the difficulties SHRP researchers will have in using the data, because the amount and type of data from each site will be different.

Because of the volume and complexity of the traffic information collected for the SHRP LTPP project as a result of this data collection plan, a separate database, the National Traffic Database (NTDB) has been designed to store and maintain the majority of the traffic information that will be collected for each GPS and SPS site. From this traffic database, summary information will be transfered to the national pavement database (NPPD). SHRP researchers will have access to traffic data both at the summary level (through the NPPD and the NTDB) and at the detailed level (through the NTDB). The flow of information within the SHRP program is illustrated in Figure 1.

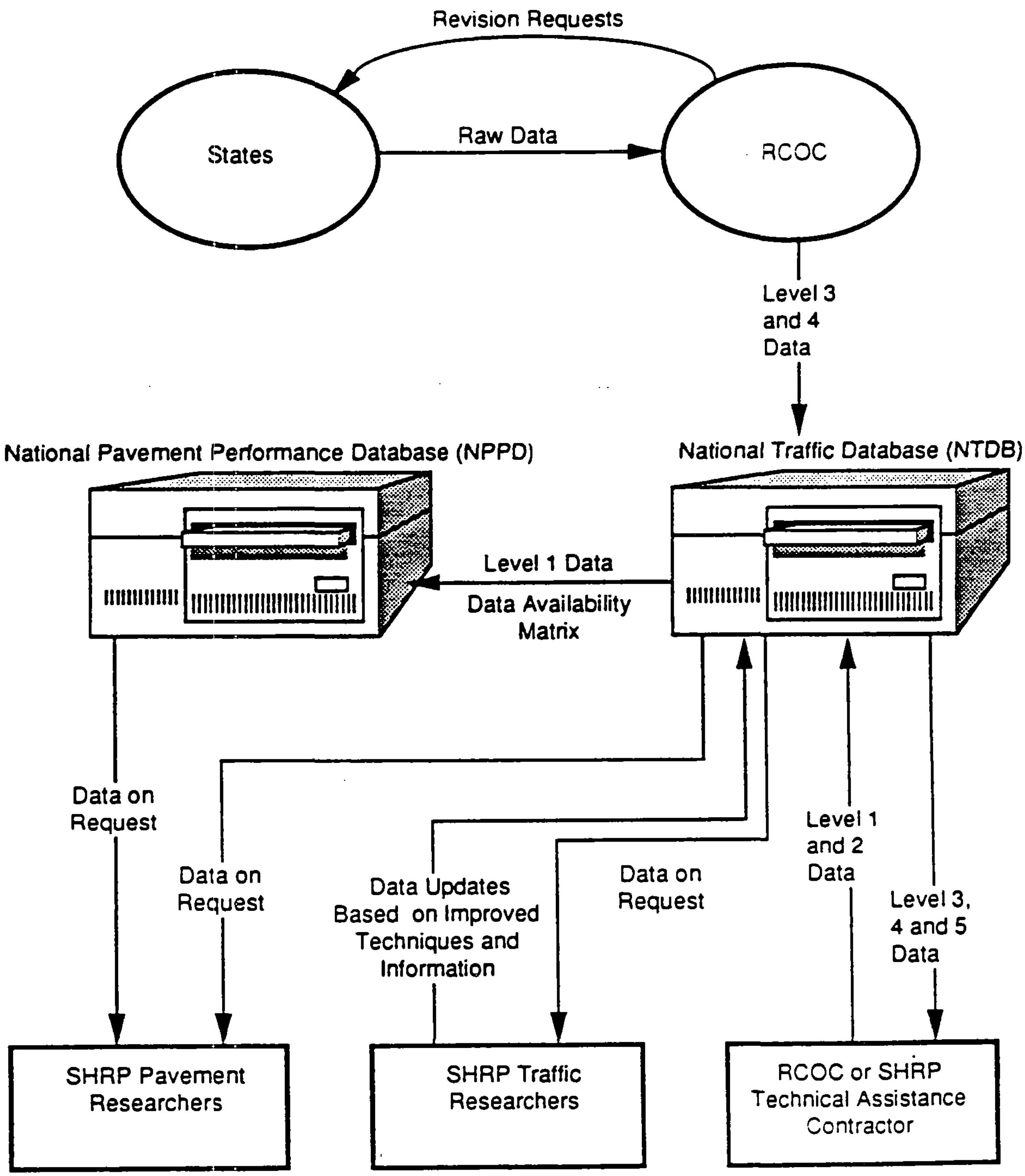

Figure 1. Databases, Information Sources and Their Interaction

TRAFFIC DATA IN THE NPPD

The traffic data in the NPPD will consist of the loading estimates shown in Figure 2. The records in this file will represent SHRP's best estimate of the loads experienced by each SHRP study section for each calendar year since the particular pavement section opened to traffic. The loading estimates will be given as the number of axles by weight range that the SHRP section experienced that year, by type of axle (singles, tandems, triples and quads). In addition, the combined Equivalent Single Axle Load (ESAL) for these axles will be computed with the AASHTO ESAL formula, based on the SHRP study lane pavement type, and will be stored in the record. A number of other supporting variables will also be included in the data record.

Maintaining the pavement loadings by axle load will allow researchers to examine alternative ESAL computation formulas, while storing the ESAL value computed with the current AASHTO formula will provide researchers with a "quick and easy" load estimate if that is what they desire for a specific analysis.

To help describe the traffic data available to SHRP researchers and to provide information on the number of traffic data used to calculate the annual conditions described in the file, the NPPD will also contain a description of the traffic data that have been collected at each study site. This part of the NPPD is called the "Data Availability Matrix." It is also included as part of the national traffic database. An example of the data availability matrix is shown in Figure 3.

The matrix will be included in the NPPD to allow researchers to identify those SHRP sections that have a strong traffic database and the sections that have very little traffic information. The matrix may also be used to determine which SHRP study sites have sufficient quantities of traffic information available to perform specific analyses that require more detailed data than can be found in the NPPD (e.g., which sites have measured traffic loads during specific seasons).

FIGURE 2
TRAFFIC DATA IN THE NATIONAL PAVEMENT PERFORMANCE DATABASE

Study site location ________
Year ________
Study site lane volume________ Standard Dev. of Volume Est. _______
Sample Size (N) for Vol. Est. _______
Data availability code ________

Single axle weight distribution
Single axles counted _________ Single axles weighed _______
Single axles estimated for the year ________
weight category 1: Definition ______ Number of Axles ______
weight category 2: Definition ______ Number of Axles ______
etc.

Tandem axle weight distribution
Tandem axles counted _________ Tandem axles weighed _______
Tandem axles estimated for the year ________
weight category 1: Definition ______ Number of Axles ______
weight category 2: Definition ______ Number of Axles ______
etc.

Triple axle weight distribution
Triple axles counted _________ Triple axles weighed _______
Triple axles estimated for the year ________
weight category 1: Definition ______ Number of Axles ______
weight category 2: Definition ______ Number of Axles ______
etc.

Quad + axle weight distribution
Quad + axles counted _________ Quad + axles weighed _______
Quad + axles estimated for the year ________
weight category 1: Definition ______ Number of Axles ______
weight category 2: Definition ______ Number of Axles ______
etc.
Total Number of Truck & Combinations ________
Standard Dev. of Truck Vol. Est. ______ Sample Size (N) for Truck Vol. Est. ______

Annual ESAL for study site this year ____ Standard Dev. of ESAL Est. _______
Weighted N for ESAL estimate _______

SN (structural number) for study site this year ______
D (depth of concrete pavement) ______
Number of historical modifications (version number) ________
Code for method used to estimate AADT ________
Date this update was created ______
Construction Event code _______ Date of Construction Event ________
Comments ____

Repeat this record once for each year since the pavement section was opened for traffic. The entire set of records is then repeated for each study site.

FIGUIRE 3

MATRIX OF AVAILABLE TRAFFIC DATA

SITE NUMBER: ________

Year	Short Volume Counts	Continuous Volume Counts	Short Vehicle Class Counts	Continuous Vehicle Class Counts	Short WIM Counts	Continuous WIM Counts	Data Availability Code
85	two						0
86	four						0
87	four		one		one		2
88			two				2
89		by lane		by lane		by lane	9
90		by lane		by lane		by lane	9

TRUTH IN DATA

Because the data stored in the NPPD will come from a variety of sources and will represent a variety of levels of statistical precision, the Traffic ETG felt that all data included in the database should be strictly defined and labeled to describe qualitative and quantitative differences. That is, a researcher using the SHRP database should be able to define the quality and quantity of data needed for a particular experiment and restrict his/her analysis to those sites that have produced data meeting those requirements.

To meet this need, the Traffic ETG has developed a descriptive scale that labels the quantity of information available in the dataset for any SHRP site. A list of these codes is shown in Figure 4. In addition, as sufficient data become available, statistical parameters (means, standard deviations and sample sizes) that quantify summary variables will be computed and stored in the database so that researchers can estimate the reliability of the calculations made with the available traffic data.

TRAFFIC DATABASE DESCRIPTION

To facilitate the use of the database, all information in the database will be stored by site ID. That is, the information will be stored in a relational way, with the primary relationship between the data being the GPS or SPS site number. Data appropriate for any level of research can be requested by SHRP researchers through either the NPPD or the NTDB.

The traffic database will be divided into five levels of information. Each level will represent a different aggregation of the traffic data. Each of these levels of data will serve a different purpose and will be useful to a different group of researchers.

The five database levels are as follows:

- Level 1 - Primary Loading Estimates,
- Level 2 - Annual Traffic Estimates by FHWA Classification Scheme,
- Level 3 - Daily Traffic Counts,

FIGURE 4

DESCRIPTIVE DATA AVAILABILITY CODES

Code	Description
9	Conventional WIM (load cell or bending plate) operating continuously at the SHRP site.
8	Low cost WIM (piezo-electric, bridge, etc.) operating continuously.
7	Permanent vehicle classifier operating continuously, with portable WIM for all seasons and weekday/weekend time periods
6	Continuous vehicle classification with some seasonal site specific WIM measurements.
5	Continuous vehicle classification with limited site specific WIM
4	Continuous ATR volume station, with limited site specific vehicle classification and truck weight data and a site specific measure of truck seasonality.
3	Site specific vehicle classification and site specific WIM with some site specific measure of seasonality
2	Limited site specific data (only short duration counts) for either vehicle classification or truck weights
1	Site related data, adjusted for intervening intersections
0	No site specific or site related vehicle classification or truck weight data

- Level 4 - Detailed Traffic Measurements. and
- Level 5 - Supporting Data.

The data in each of these levels and the intended uses of those data are described below.

Level 1 - Primary Loading Estimates

This level of the database will contain the summary data to be transferred to the NPPD. It has been designed to provide an easily obtained "best estimate" of load on the study section. This level of traffic information will be sufficient for the vast majority of LTPP pavement performance studies.

Level 1 data records will consist of the following elements:

- annual estimates of total axle loadings for the study lane,
- annual automobile and truck volumes for the study lane,
- measures of the statistical variability of the data, and
- a computed ESAL value for those axles.

An entry will be present in the database for each study site (both GPS and SPS) for each year since the pavement was opened for traffic. The values presented in the database will be SHRP's "best estimate" of the annual totals for that site, given the data submitted by the state or provincial highway agency (SHA) for that site. Because traffic levels are variable and traffic information is limited, the database has been designed so that authorized SHRP contractors may revise these load estimates if additional data collection shows that the initial estimates may be improved with newly available data or alternative mathematical techniques.

Level 2 - Annual Traffic Estimates By FHWA Classification Scheme

Like Level 1, this level of the database will contain estimates of annual traffic volumes and axle load distributions in the study lane for each of the LTPP study sites. Level 2 of the database differs from Level 1 in that the number and weight of axles will be stored by FHWA vehicle class for each year at each LTPP site, rather than for all vehicle classes combined. This level of the database is designed to allow a more detailed examination of the loading history of an LTPP study site. with particular emphasis on the number of vehicles by vehicle type that cross the study section and the distribution of axle weights that occurs within those vehicle types.

As with Level 1, these values will be SHRP's "best estimate" of annual traffic loadings. The estimates included in the file will contain loadings for only the SHRP study lane. SHRP contractors will develop these estimates by using the traffic information submitted by the SHAs and the best available statistical techniques.

As with Level 1 estimates, the Traffic ETG anticipates that as more data become available and techniques for estimating annual conditions from limited data mature, SHRP will revise the estimates of annual traffic loadings contained in this part of the database. These revisions will only be performed by authorized SHRP contractors.

Level 3 - Daily Traffic Counts

This level of the database will contain daily totals of the traffic measurements submitted by the SHAs for truck weights, total volumes, and vehicle volumes by vehicle classification. Only that traffic data physically collected and submitted by the SHAs will be present in this file. Data at this level of the file will not have been factored, modified, or adjusted by either the submitting SHA or SHRP.

This level of the database is intended to allow detailed analysis of the traffic data used to estimate the annual totals. It is specifically designed to show the researcher which data are "real" and which data are "interpreted" so that individual researchers can make their own assumptions about how limitations in the available traffic data should be overcome. This level of data will also be used as the starting point for research into different methods for producing annual traffic estimates from short duration count data. This level of the database will also be required to provide estimates of seasonal loadings for LTPP researchers who need to separate loadings for particular time periods as opposed to the annual conditions presented in database Levels 1 and 2.

In Level 3, up to 365 records for each type of data (volume, weight or class) may be present in the database for each LTPP site for each year since the site was opened for traffic. Records will only be present in the database for days on which an SHA actually collected data, or where a record is necessary to inform a researcher that no data were collected at that site for an entire calendar year.

"Missing data" will not be inferred or entered into this level of the database. Space on the data records will also be supplied for an SHA to provide additional information pertaining to this count. "Additional" information may include any "factors" a state might ordinarily use to estimate annual totals based on that count, or comments about events that may have an impact on how that particular count should be used by SHRP or a SHRP researcher. The database will store information for both the SHRP study lane and all other lanes for which an SHA submits information.

Level 4 - Detailed Traffic Measurements

This level of the traffic database will contain the hourly traffic counts and individual truck weight records that were collected and submitted by the SHAs. As with Level 3, no modifications or adjustments will be made to these data. Similarly, no gaps in the data submitted will be filled in by either SHRP or the SHAs.

These raw records will be kept to allow the recreation of the previous levels of the database and to allow SHRP researchers to examine traffic loads at a detailed level. For example, load patterns of specific truck types could be examined using this level of the database. Similarly, traffic loading patterns by time of day could be analyzed from the hourly records. This level of the database will also be required to maintain the integrity of the database as part of the "truth-in-data" concept.

As with Level 3, three different record types will be used to store volume, class, and weight data. A fourth type of record maintained at this level of the traffic database will contain information specific to the weigh-in-motion scale used to collect the truck weight data. This information will describe the site and equipment used to collect WIM data. It will be included in the SHRP database because both the type of scale and the site characteristics for that scale impact the vehicle weights recorded by that device. The ETG believes that this information will benefit researchers when they examine the differences caused by using WIM scales (as opposed to static scales) in pavement performance equations.

Level 5 - Supporting Data

This level of the traffic database will contain all of the supporting information for each study site, inlcuding the data availability matrix. In addition to the functions described earlier in this report, this matrix will track the entry, current status, and current location of all data submitted for each study site.

The matrix will serve two primary purposes. 1) It will serve as an automated index for accessing any data included in the database, and 2) it will allow any researcher to quickly determine which traffic load estimates at LTPP sites are supported by large quantities of data and which are supported by relatively few data.

Level 5 will also contain the following types of data:

- data on the traffic impacts of intersecting roadways (that is, intersections that lie between a traffic data collection site and the LTPP section);
- traffic data collected from locations not on the same highway as the LTPP site, but which are used to help estimate traffic loadings on an LTPP study site;
- traffic measurements collected at the LTPP sites but summarized by the SHAs before the SHRP instructions were developed and which can not be placed in the Level 4 data record format; and
- truck weight information at WIM sites that are not part of the LTPP study, but which will be used in the analysis of regional patterns of truck travel.

With the exception of the data availability matrix, most of the data stored in this level of the database will be of interest only to traffic researchers and SHRP contractors in charge of developing the Level 1 and 2 traffic loading estimates. However, it will be available to all SHRP researchers.

USE OF THE LTPP TRAFFIC DATA

The LTPP traffic database will be among the most comprehensive traffic databases ever assembled. Analyses of these data will begin to provide answers to many of the most basic questions about traffic. Using the database, SHRP researchers should be able to respond to questions like the following.

- How "accurate" are estimates of annual ESAL loadings based on a few short duration measurements?
- How variable are truck weights throughout the year?
- How variable are truck volumes throughout the year?
- What changes are occuring in the truck fleet currently operating on our highways, and what impact will those changes have on our estimates of axle loads for new pavement?
- What level of traffic counting should be made at a site to accurately measure the existing traffic levels?
- What level of confidence (reliability) should we have for the traffic estimates used in pavement design and pavement research?

Current traffic monitoring practices have relied on a few counts of trucks and the occasional weight session to estimate truck traffic and loads. Many times, assumptions such as "truck volumes don't change by month" or "truck volumes change at the same rate as automobile volumes" are made so that short duration counts can be adjusted to represent annual estimates. Few data have been available to dispute or verify these assumptions, yet they play a very large part in the estimation of loads for a road and an important part in determining the design of that pavement.

For example, data collected in Minnesota shows that 3S2 truck traffic (often assumed as the most "stable" of the truck volumes) not only varies over the course of a year, but the pattern of variation can be quite different from one location to another (see Figure 5). Similarly, ESALs applied by those trucks also change over the course of a year (Figure 6). Even within the course of the "average" week, the patterns of 3S2 truck volumes and loads differ significantly (see Figures 7 and 8). Perhaps more importantly, the patterns for volumes and loads move in opposite directions on the weekends. (There are fewer trucks, but they weigh more.)

With the help of emerging technologies and the need to accurately assess truck volumes and axle loadings for the LTPP, sufficient data will be collected to examine these assumptions. The findings of these investigations will undoubtedly result in changes to the way we treat traffic for the design of pavements. Providing the data and the methodologies to perform these analyses and developing the techniques for applying them to both the SHRP LTPP research efforts and the general process of pavement design will be the main thrust of research with traffic data collected by SHRP.

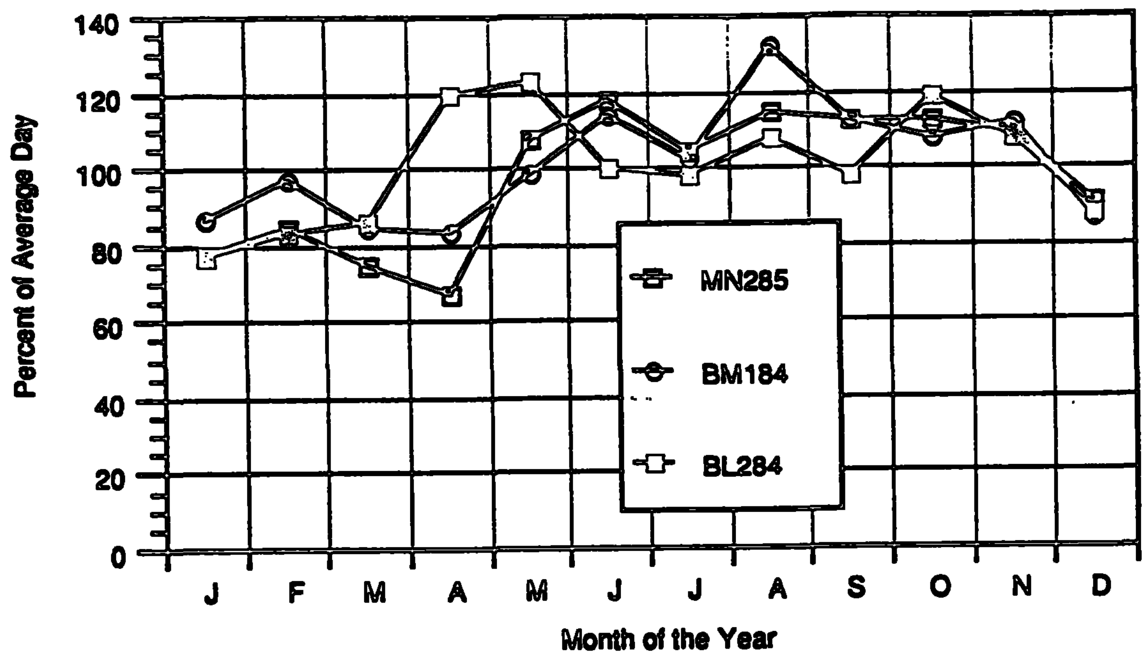

Figure 5. Average Daily 3S2 Volumes by Month

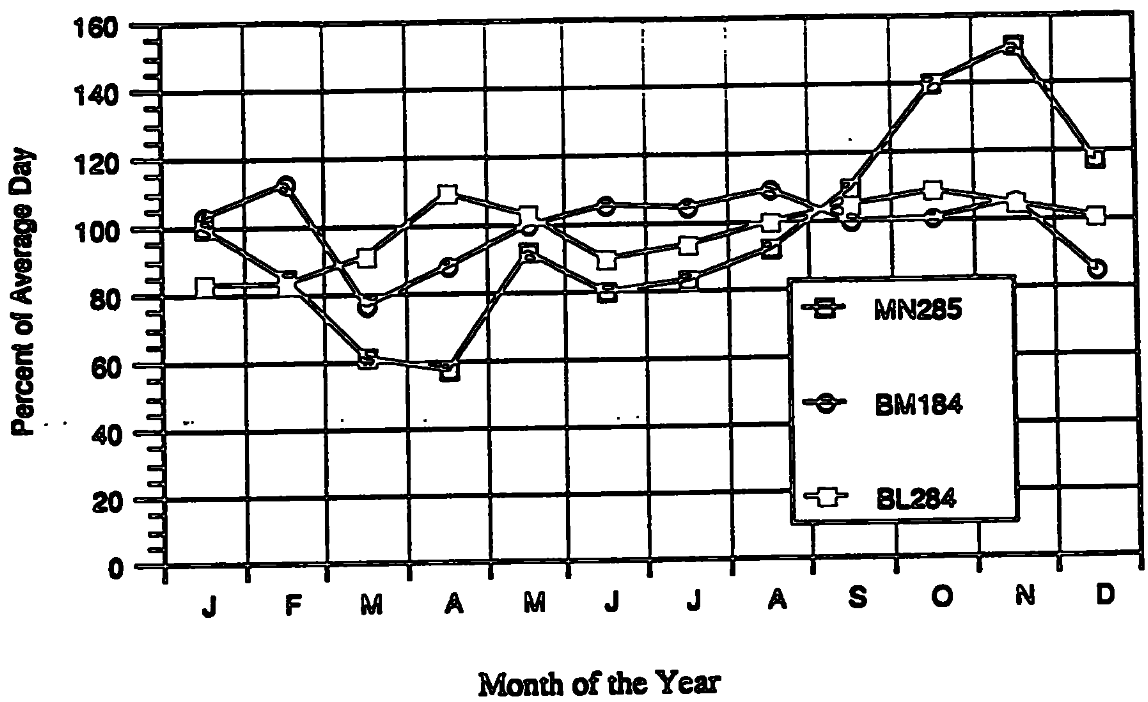

Figure 6. Average Daily 3S2 ESAL by Month

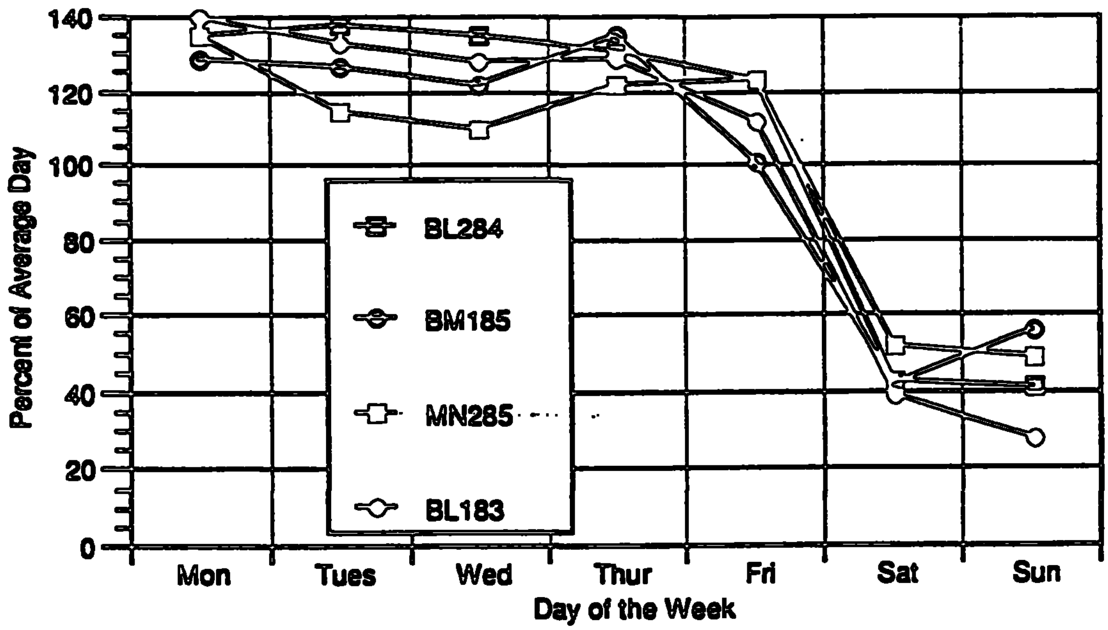

Figure 7. 3S2 Volumes by Day of Week

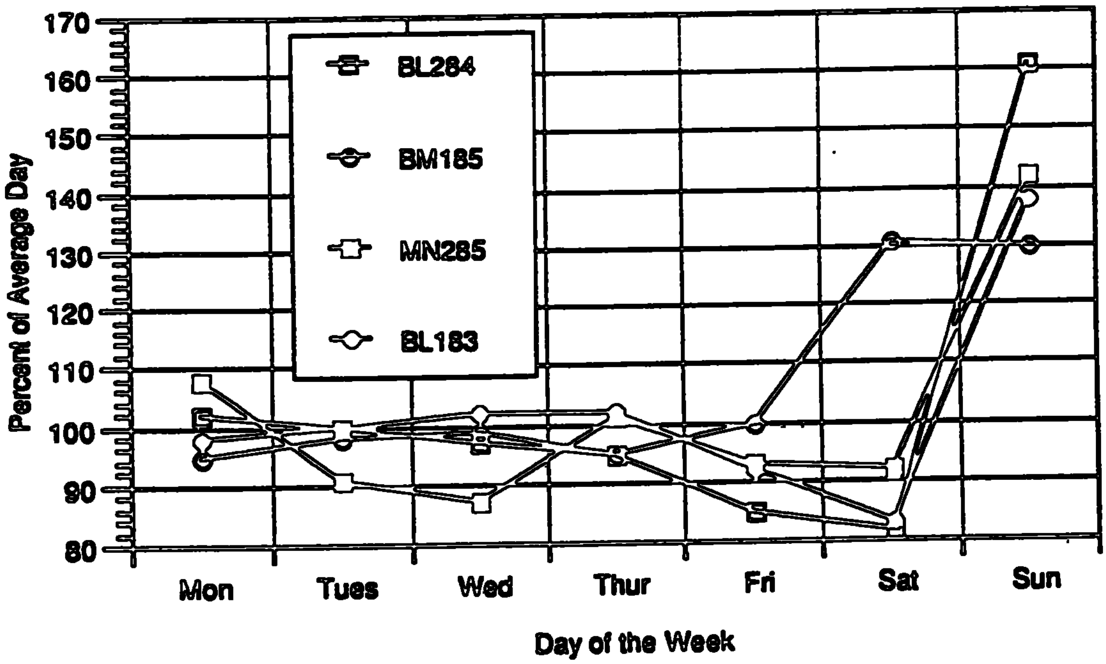

Figure 8. ESAL Loads for 3S2's by Day of Week

USING LTPP TO EVALUATE CURRENT DESIGN METHODS

Paul Irick, TRDF

PURPOSE

One of the six LTPP objectives is to evaluate various flexible and rigid pavement design methods with data collected from GPS and SPS test sections.

The purpose of this presentation is to discuss how observed data from LTPP studies can be used to evaluate and calibrate distress/performance prediction equations that are relevant to current methodology for pavement design. Our presentation is based on a TRDF technical memorandum that was developed by the author and Robin High in 1989.

Available prediction equations have been developed through various combination of laboratory and field studies, including the AASHO Road Test, but virtually none has been evaluated over the wide range of independent variables that is provided by the LTPP studies. A major part of the LTPP objective is, therefore, to determine how well the available equations agree with LTPP data, and to infer if and how any or all of these equations can be adjusted to provide satisfactory agreement with the LTPP data. It seems reasonable to suppose that the evaluation and calibration of existing equations will provide much information and insight towards the development of new prediction equations for virtually all indicators of pavement distress and performance.

TYPES OF DESIGN EQUATIONS

Basic elements of pavement design methods and associated design equations are shown in Figure 1. As shown at the bottom of the figure, an essential component of pavement design is a prediction equation for each type of pavement distress that is included in the design criteria. The independent variables (or predictors) in these equations represent specific traffic factors, environmental factors, and structural properties, either explicitly or implicitly through pavement response variables. Each GPS and SPS has been designed to supply values for major predictors of pavement distress and performance.

As shown down the left side of Figure 1, for mechanistic-empirical design methods, each distress prediction equation contains one or more pavement response variables (deflections, strains, stresses) whose values are determined by structural models (e.g., elastic layer or finite element programs). In these cases many, but perhaps not all, of the loading, environmental, and structural factors are subsumed by the response variables, and the distress prediction equation is said to be a transfer function for pavement response. Whether or not response variables are used to predict distress, the distress equation must be derived empirically from field studies that provide observations on the progression of distress with time and load applications.

For completely empirical design methods, the distress/performance equations contain no response variables and have been derived from observed combinations of the traffic, environmental, and distress predictors.

The direct version of a distress prediction equation predicts the expected degree of distress after any particular time period and accumulated load applications. If the direct equation is used, the design process begins with a trial pavement structure for which distress predictions are made. If distress criteria are not met, structural modifications and new distress predictions are iterated until a satisfactory pavement design is reached.

The indirect (or inverted) version of a distress equation predicts the length of time and/or number of applications for given levels of distress, including so-called failure or terminal levels. If performance is defined to be the time and/or applications for which distress remains at permissible levels, then the indirect versions are performance prediction equations. If both the terminal distress level and the corresponding accumulated applications are specified, then alternatives can be determined for structural designs that satisfy the performance prediction equation.

It is noteworthy that GPS data will general provide data for evaluating direct versions, but that evaluation of indirect versions will generally require SPS data. This is because the GPS data will not include numbers of load applications that correspond to specific terminal distress levels for all test sections in any study, whereas long-term observations of SPS test sections will eventually show when each section reaches any given distress level.

CANDIDATE EQUATIONS FOR EVALUATION AND CALIBRATION

Numerous distress prediction equations have been developed for use in pavement design and most are candidate for evaluation and calibration using LTPP data. A number of these candidate equations are shown in Table 1 for flexible pavements and in Table 2 for rigid pavements. Two leading candidates are the flexible and rigid pavement design equations that appear in the early chapters of the revised AASHTO design guide. The distress indicator in these equations is serviceability loss; both contain terms and coefficients that have not yet been evaluated in terms of large-scale field studies. The AASHO equations are given in their indirect form, i.e., as prediction equations for the number of ESALs at which specified serviceability levels are reached.

Other candidates include prediction equations for particular types of distress such as fatigue and thermal cracking, rutting, faulting, and joint deterioration. Some of these equations appear in industry-sponsored design methods, e.g., the Asphalt Institute and PCA design equations, some have been derived through state-sponsored research, e.g., by Pennsylvania and Texas, and others have resulted from NCHRP and FHWA research projects e.g., the COPES distress equations for rigid pavements and equations that were developed in the 1984 FHWA cost allocation study. Most of these equations are identified and discussed in the AASHTO Design Guide and/or in the NCHRP 1-26 project report on calibrated mechanistic design procedures.

Nearly all of the existing distress prediction equations can be evaluated, at least partially, from LTPP data. Exceptions may occur for those equations that are expressed indirectly (i.e., for prediction of "applications to failure") and that cannot be expressed directly (i.e., for prediction of distress amount). It can be expected that SPS data will eventually be available for evaluation of the indirect prediction equations.

Existing structural models for flexible and rigid pavement response predictions are also identified in Tables 1 and 2. It may be assumed that any efforts to evaluate and calibrate these models will be through the use of FWD data that are produced in LTPP studies.

EVALUATION CRITERIA

Evaluation of a particular distress equation begins by comparing the distress values (Y_c) that are predicted by the equation with corresponding observed distress values (Y_o) for all LTPP test sections to which the equation is applicable. Differences between Y_o and Y_c are prediction errors or residuals (R). If Y_c values are plotted versus Y_o values, residuals are either the horizontal or vertical distances of the plotted points from the line of equality, $Y_c = Y_o$. Illustrative residuals for a hypothetical distress prediction equation are shown in Figure 2, where the plotted points represent predicted and observed distress values for some set of GPS test sections.

Also shown in Figure 2 are evaluation criteria for the overall set of residuals. the criteria include (a) validity or lack of bias, (b) randomness with respect to the entire range of the line of equality, (c) homogeneity of residuals across the range, (d) normality of the residual distribution, and (e) the magnitude of the root-mean-square residual. Statistical procedures can be developed for quantifying the degree to which these criteria are met. Evaluation statistics will reflect significant differences between the line of equality and the trend exhibited by the plotted points.

If the set of residuals meets all criteria, it may be inferred that the prediction equation is suitable for representing the LTPP data and needs no further adjustment. If one or more of the criteria are not met, there will be rather specific indications of both the equation's weaknesses and the steps that may lead to significant improvements.

In the Figure 2 illustration it can be seen that the predictions are biased and non-random with respect to the line of equality. It follows that the equation needs adjustment (and perhaps the inclusion of additional predictors), before it can provide agreement with the GPS observations.

In addition to analysis of the overall set of residuals, separate residual analyses need to be made for the effects of each predictor (X_i) in the prediction equation. It can be, for example, that the evaluation criteria are met for the overall predictions, but that predictions for the effects of individual predictors are biased, say in one direction for X_i and in another (compensating) direction for another predictor, X_j. Thus the residual evaluation criteria should also be met for the individual and interaction effects of each pair of predictors.

An illustration of the differences between observed and predicted effects for two predictors is given in Figure 3. The vertical scale is for the values of some particular distress indicator after (say) two million ESALs have been experienced by each test section. The horizontal scale is for a specific indicator (X_i) of subgrade "strength," and curves are shown for the distress prediction equations sensitivity to X_i for two levels of a second predictor (X_j) that represents climatic "adversity." It is assumed that all other predictors in the prediction equation are at fixed levels.

The plotted points (squares and circles) represent four GPS test sections in each of the two climates, and residuals are shown for the differences between predicted and observed values of distress. In this example it is fairly clear that the observations show less effect of soil strength than predicted, but that the climate effect (i.e., vertical differences between the two curves and between squares and circles) is similar for both predictions and observations. Thus the evaluation criteria might be met for climate but not for soil strength.

This example has been used because it is generally recognized that the LTPP studies will provide new and much-needed knowledge of the effects of soil and climate on pavement distress and performance.

CALIBRATION OF PREDICTION EQUATIONS

Calibration of an existing distress prediction equation to LTPP data implies adjustments that may include the mathematical form of terms in the equation, coefficients for individual terms or sets of terms, and the inclusion of additional predictors that are available in the LTPP data.

One general approach to calibration is to derive an adjustment function (or shift factor) for the original prediction function. As shown in Figure 4, the original function can be represented by $Y_c = F(X_p)$ where X_p is the set of predictors contained in the function and Y_c is the prediction for a distress variable, Y. Residuals for the original function are $R = Y_o - F(X_p)$ where Y_o is the observed value of Y. The evaluation of these residuals may indicate the need for new forms or adjusted coefficients for some subset (X_p^1) of the original predictors, and may indicate dependence of the residuals on additional predictors (X_q) that are available in the LTPP database. Thus the original residuals may be explained to a certain degree by an adjustment function, $G(X_p^1, X_q)$, for the original function. The adjusted prediction function is, therefore,

$$Y_c^1 = F(X_p) + G(X_p^1, X_q)$$

where Y_c^1 is the new prediction for Y, and the new residuals are $R^1 = Y_o - Y_c^1$. If the new residuals meet the evaluation criteria, for both overall predictions and for the effects of individual predictors, then the calibration has been successful and Y_c^1 is a satisfactory distress prediction equation for LTPP data, at least with respect to the evaluation criteria.

If the calibration is not successful, the original prediction equation may be unsuitable for representing LTPP data, and it may be necessary to develop a new equation that embodies what has been learned from the evaluation and attempts to calibrate the old equation.

SUMMARY REMARKS

The use of LTPP data to evaluate existing prediction equations that are useful in pavement design can show the strengths and weaknesses of each equation with respect to both overall predictions and effects of individual predictors and their interactions. Evaluation and calibration together can produce significant improvements for existing equations and/or specific direction for the derivation of new prediction equations from LTPP data.

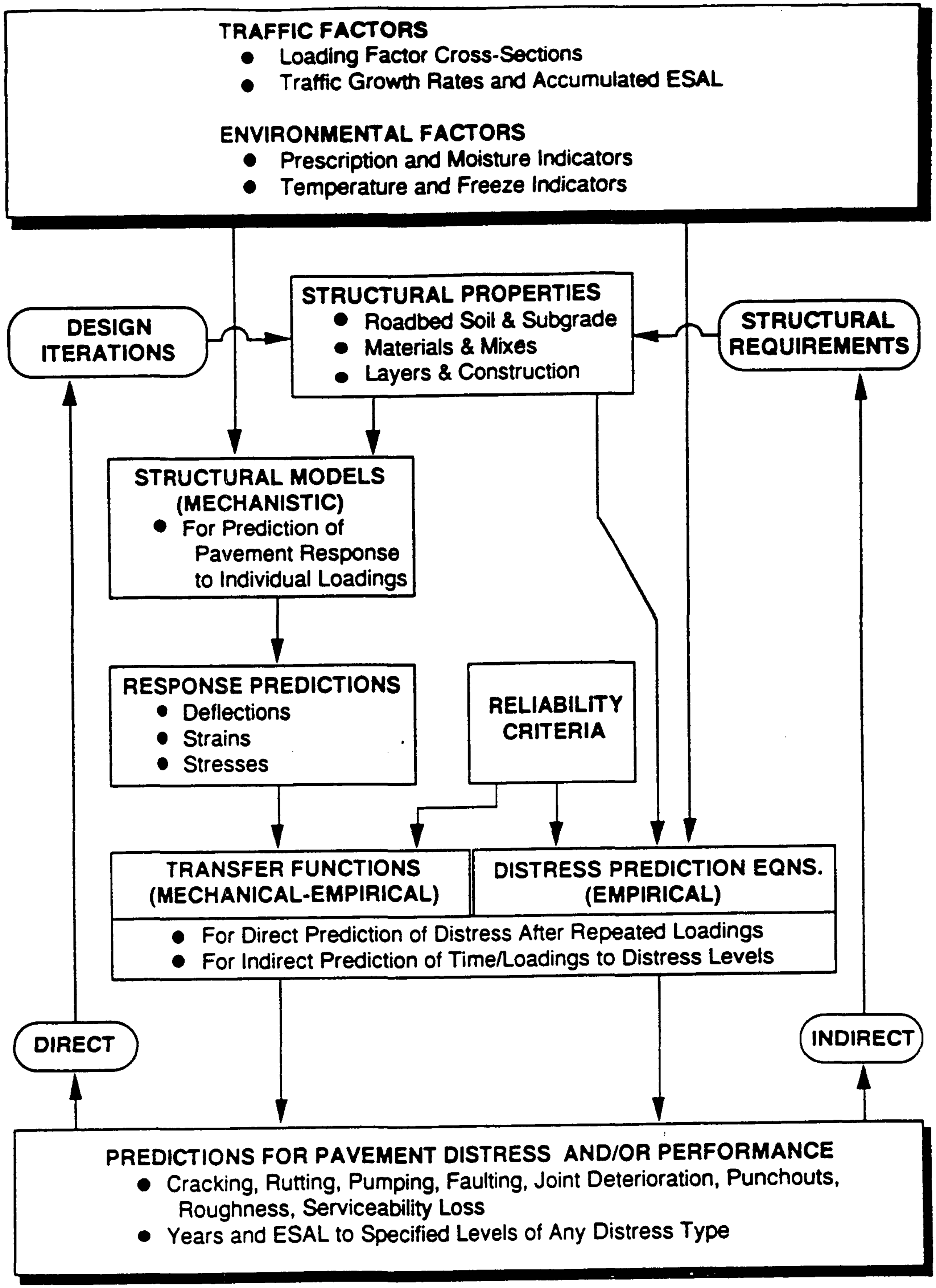

Figure 1. Methods and equations for pavement design.

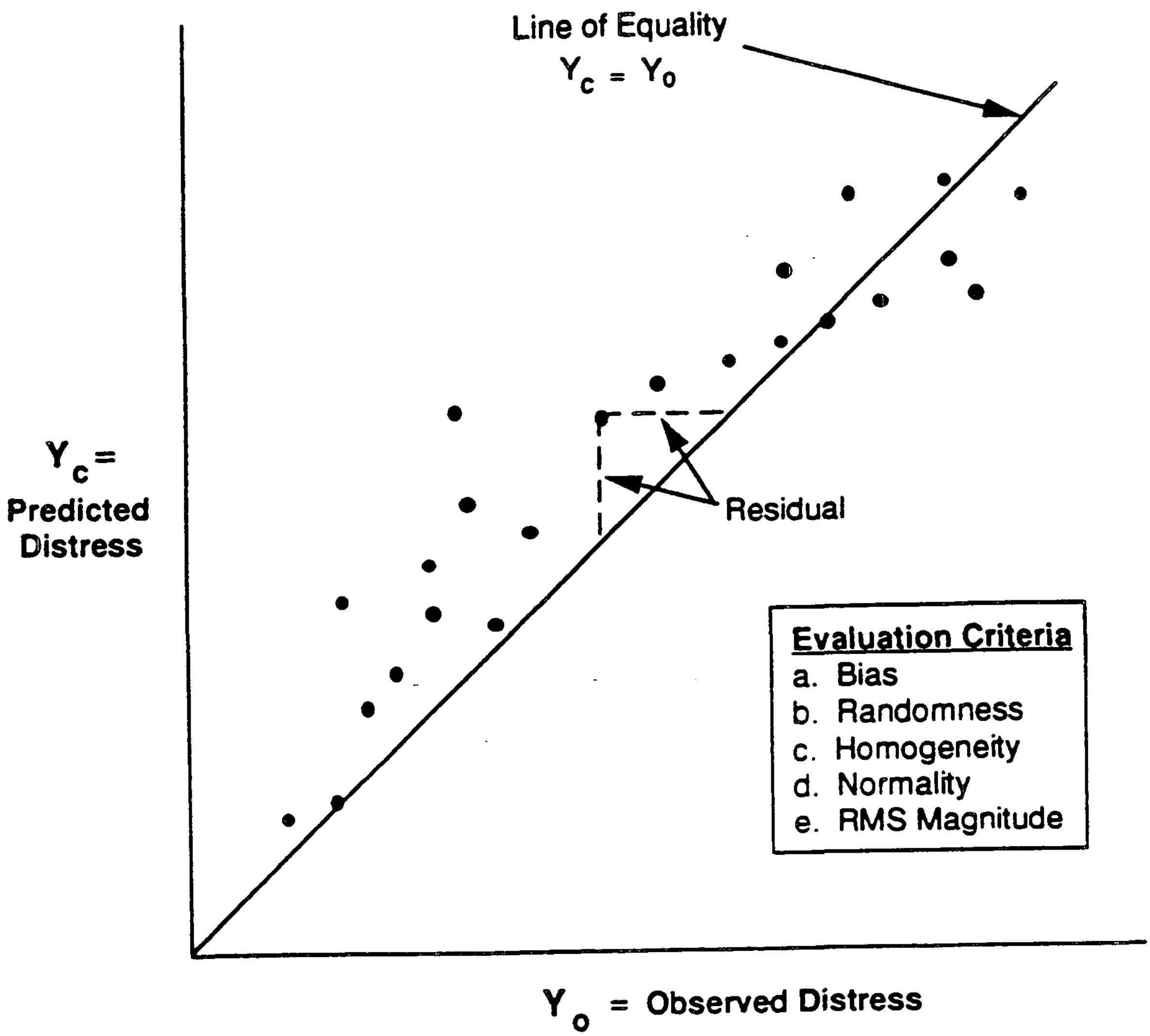

Figure 2. Illustrative residuals and evaluation criteria for distress equation predictions.

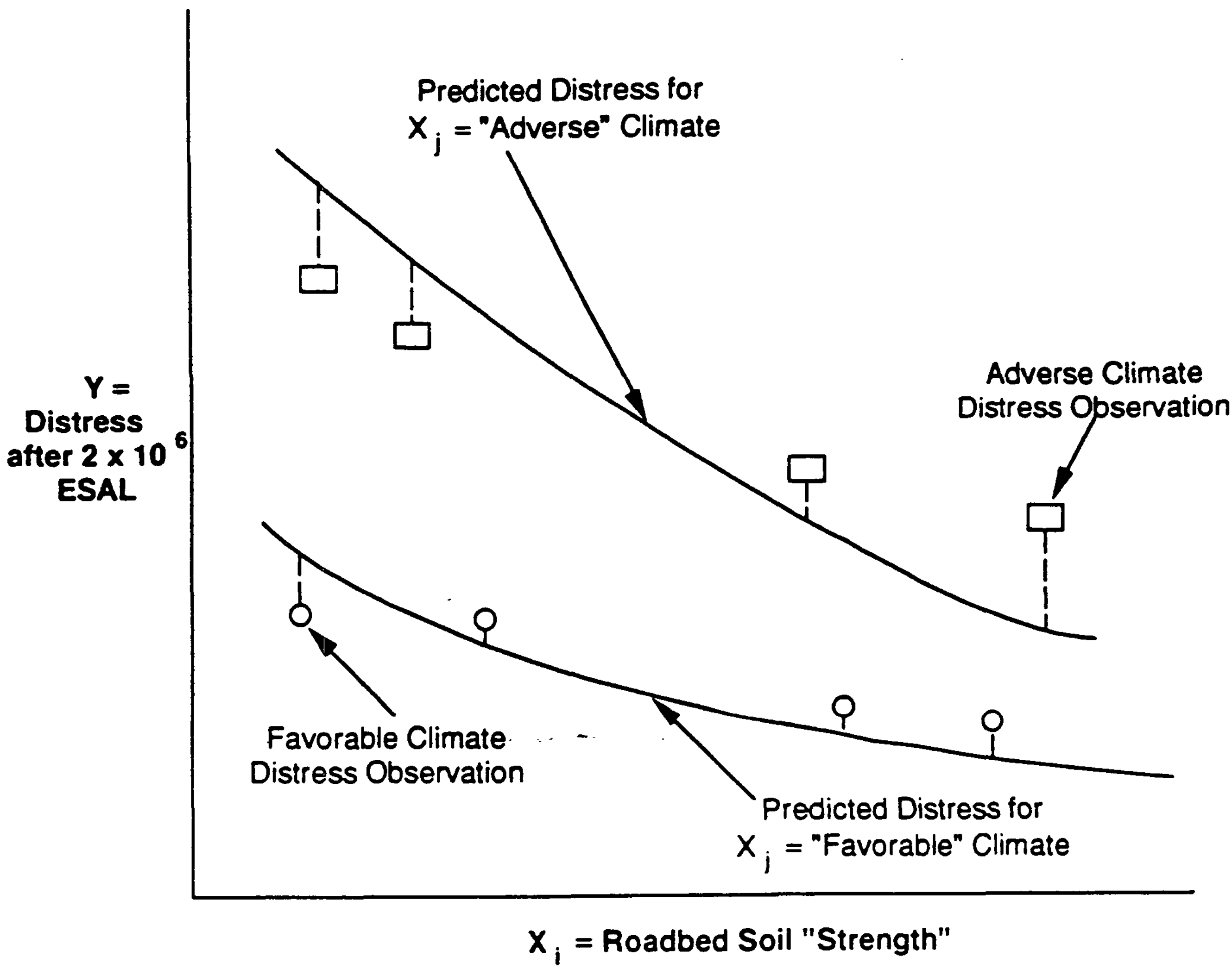

Figure 3. Illustrative comparison of predicted and observed effects of two predictors.

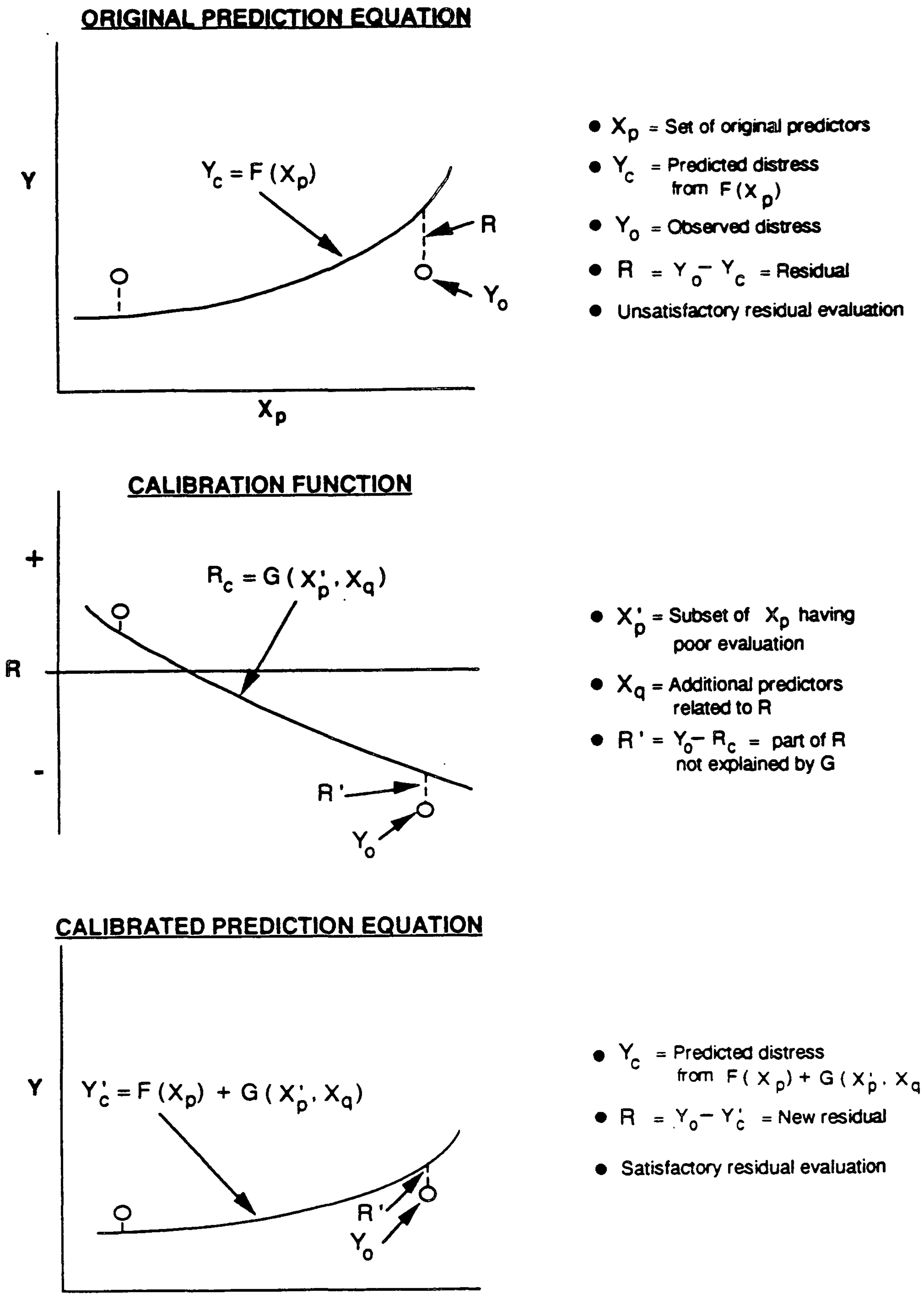

Figure 4. Calibration of prediction equations.

Table 1   Candidate flexible pavement design equations for evaluation/calibration using LTPP data.

TYPE OF PREDICTION EQUATION OR ALGORITHM		F1. Structural Models for Pvt. Response to Load		F2. Transfer Functions for Predicting Flexible Pavement Distress After Repeated Loadings										
		F11. Elast. Layer	F12. Finite Element	F21. Thermal Cracking		F22. Fatigue Cracking			F23. Transverse Rutting			F24. Serviceability Loss or Roughness		
REFERENCES * FOR SPECIFIC PREDICTION EQUATIONS/ALGORITHMS		F111-F116* BISAR, CHEVRON, etc	F121 * ILLI-PAVE	F211 * Shahin-McCullough	F212 * Hajek-Haas	F221 * Asphalt Institute	F222 [illegible] Freeman	F223 Texas FPDS	F231 * Shell	F232 DBL	F233 * [illegible]	F241 AASHTO Design Guide	F242 Texas FPDS	F243 Fernando
OUTPUT PREDICTION (DEPENDENT VARIABLE)		Deflections, Strains and Stresses		Thermal Cycles to Fail	Cracking Index	Load Apps. at 20% Crack	Load App. at Failure	Degree of Cracking	Rut Depth	Rutting Rate	Pavmnt. Strain	PSI at WESAL	PSI at WESAL	Slope Var at WESAL
DATA STATUS (SEE LEGEND)		E (Via FWD Data)		??	E (Survey)	??	??	E	E	E	E	E (Via Profile & Summary)		E (Profile)
AGE & LOAD	Pavement Age				E									
	Axle Load Factors	E	E			E Traffic Distribution Needed to Estimate Current and Cumulative ESAL								
	Cumulative ESAL					E	E	E	E	E	E	E	E	E
ENVIRONMENT	Moisture Indicators							E						
	Temperature Indicators			E	E			E	E	E	E			
	Freeze Indicators							E						
AC SURFACE LAYER	Deflection/Strain/Stress			E		E	E		E	E	E		E	E
	Initial Profile											??		??
	AC Thickness	E	E		E			E	E			E	E	E
	AC Stiffness	E	E	E	E	E		E	E	E				
	AC Strength						E							
	AC Mix Factors				E	E			E	E				
BASE LAYER	Deflection/Strain/Stress													
	Base Thickness	E	E					E				E	E	E
	Stiffness	E	E					E						
	Strength/Stability													
	Drainage Factors													
SUBBASE LAYER	Deflection/Strain/Stress													
	Subbase Thickness	E	E					E				E	E	E
	Stiffness	E	E					E						
	Strength/Stability													
	Drainage Factors													
ROAD BED SOIL	Deflection/Strain/Stress													
	Subgrade Stiff.	E	E					E						E
	Strength/Stability							E						
	Gradation				E								E	

EQUATION INPUT (INDEPENDENT) VARIABLES

* Reference is Discussed in NCHRP 1-26 Report

CELL LEGEND:

Variable is in Equation and:
- E — LTPP data are generally available
- ?? — LTPP data are not generally available

Variable is not in Equation and:
- (white cell) — LTPP data are generally available
- (black cell) — LTPP data are not generally available

Table 2. Candidate rigid pavement design equations for evaluation/calibration using LTPP data.

TYPE OF PREDICTION EQUATION OR ALGORITHM		R1. Structural Models for Pvt. Response to Load — R11. Finite Elm. Prog.		R2 Transfer Functions for Predicting Rigid Pavement Distress After Repeated Loadings — R21 Pumping	R22 Fatigue Cracking		R23 Faulting	R24. Joint Deterior.	R25. CRC Punchouts	R26. Serviceability or Roughness	
REFERENCES * FOR SPECIFIC PREDICTION EQUATIONS/ALGORITHMS		R111. * ILU-SLAB	R112. * ILU-SLAB Approx.	R211 * NCHRP 1-26	R221 * NCHRP 1-26	R222. COPES	R231 * NCHRP 1-26	R241 COPES	R251 * CRC Distress	R261. AASHTO Design Guide	R262. COPES
OUTPUT PREDICTION (DEPENDENT VARIABLE)		Deflection, Strains and Stresses		Pumping Index	Fatigue Damage	Crack Length	Mean Transvrs Fault	Percent Deterior. Joints	Punch-outs	PSI at WESAL	PSR at WESAL
DATA STATUS (SEE LEGEND)		E (Via FWD Data)		E	E	E	E	E	E	E	E
EQUATION INPUT (INDEPENDENT) VARIABLES — AGE & LOAD	Pavement Age					E		E			E
	Axle Load Factors	E	E		??						
	Cumulative ESAL			E		E	E	E		E	E
ENVIRONMENT	Moisture Indicators			E							E
	Temperature Indicators				??	E		E			E
	Freeze Indicators					E		E			E
PCC SURFACING LAYER	Deflection/Strain/Stress				??	??	??		E		E
	Initial Profile									??	
	PCC Thickness	E	E	E		E	E			E	E
	PCC Modulus	E	E				E		E	E	E
	PCC Strength				E	E				E	E
	Reinforcement Factors					E			E		
	Dowel/Joint Factors	E	E	E		E	E	E		E	E
	Shoulder Factors										
	Aggregate/Mix Factors								E		
BASE LAYER	Deflection/Strain/Stress										
	Base Thickness	E	E								
	Base Stiffness	E	E								
	Base Strength/Stability										E
	Base Erodability			E		E					
	Gradation										
	Drainage Factors			E						E	
ROAD BED SOIL	Deflection/Strain/Stress										
	Stiffness	E	E				E			E	
	Strength/Stability				E						
	Gradation			E		E		E			

* Reference is Discussed in NCHRP 1-26 Report

CELL LEGEND:

Variable is in Equation and:
- E — LTPP data are generally available
- ?? — LTPP data are not generally available

Variable is not in Equation and:
- (blank cell) — LTPP data are generally available
- (black cell) — LTPP data are not generally available

Strategic Highway Research Program

Summer Workshop

August 1, 1990, Denver, Colorado

International Experiments

A Prime Example

Boris R. Hryhorczuk

We in Canada hold the strong belief that international cooperation in the SHRP program, and more specifically in the LTPP research area, has and will continue to enhance the results of the program.

Participating countries, as well as the United States, will benefit from the cooperative programs under way in each of these nations.

Let me first address a number of the important benefits we perceive as a participating country. The first involves access to state-of-the-art research development information.

Through their active participation in the development of SHRP, national (or provincial) coordinators, contact engineers, committee members, and expert task group (ETG) members have access to prime quality information. Being involved in workshops and meetings of all kinds, they can understand the rationale behind each decision, and can better appreciate the results of the program and the limits of its application.

The rigorous time frame and the ambitious objectives of the program are forcing the experts to resolve issues and agree upon common approaches. Guidelines developed during this process are influenced by the contribution of international experts, and serve to establish international standards for research on highway infrastructures.

Standardization facilitates the exchange of research results and improves the process of communication between experts. The Distress Identification Manual, one SHRP product that is currently being reviewed prior to publication and general distribution, should contribute to international standardization and uniformity.

It is interesting to note that in just a few short years SHRP acronyms, such as GPS and SPS have become internationally accepted and used in day-to-day conversations and communications between researchers.

Common approaches to research are implemented in international complementary programs.

These are often correlated to the country's own practice, helping to bridge technology gaps among countries, and to implement SHRP procedures and products outside of the United States.

In addition to the communication links created through SHRP, direct links are established among participating countries.

Through the numerous meetings surrounding SHRP activities, informal contacts are made between experts and coordinators, and opportunities for formal cooperation and exchange programs are enhanced among participating countries.

The experience gained from hands-on involvement, and the personal and professional contacts made by international loaned staff, will serve to enhance both the individual's career when he or she returns, as well as their organization's human resource technical capability.

I believe SHRP has played a major role in improving communication and information links within the international highway research community, an initiative that could become one of the most important legacies of this entire research program.

Of course, we also believe that the United States will benefit from our and your participation in the following ways.

Research never covers all "real-life conditions", nor does it address all possible problems.

Complementary international experiments will help broaden the research scope, and will provide a wider variety of experimental conditions.

For example, research done in Canada and in the Nordic countries might help in applying SHRP results to Montana's conditions, or might address problems that appear unique to the state of Alaska.

The contribution of international experts in expert task groups, advisory committees, and as loaned staff help to better define innovative research approaches and identify state-of-the-art technology.

Deflection testing and traffic monitoring are two examples of areas where SHRP benefited from international experience and participation.

Research will typically give good results in average conditions, but information tends to become fuzzy near limit conditions.

To overcome this type of problem, the special pavement studies (SPS) program, as an example, has been designed to allow for collecting data on underdesigned and overdesigned pavement sections.

In the same way, complementary research will likely provide marginal information, as well as information beyond SHRP limit conditions, helping to refine SHRP's models under these conditions.

Representation of conditions outside of a country's own experience adds balance to the experiments. This prevents an average condition from dominating the analysis.

I'm told by people who know more about this than I do that in engineering research, we learn from the near limit conditions because mechanisms are more clearly revealed. In the great central mass, interactions mask individual mechanisms: example--thaw weakening and high surface temperature may both contribute to concrete joint distress.

The addition of international loan staff to SHRP's personnel has been an important contribution in terms of manpower and expertise.

These participants have cultivated a strong two-way communication link between SHRP and participating countries, which should ensure that highway research throughout the world will have a more common focus and the results will be more adaptable to all the players, including the United States.

Let's now look at cooperative approaches to the Long-Term Pavement Performance program.

At the present time, 10 countries have undertaken complementary LTPP programs (Japan, United Kingdom, Australia, Norway, Sweden, Finland, Denmark, Netherlands, France, and Canada). They each have their own expectations, their own context, and their own constraints. Therefore, their views of complementary pavement research vary.

So far, three main approaches have been taken to complement the U.S. LTPP program. For those countries having conditions that meet SHRP requirements, it is possible to provide sites to be integrated into the General Pavement Studies (GPS) or the Special Pavement Study (SPS) experiment, provided that characterization and monitoring can be done according to SHRP's procedures.

Canada has in part adopted this approach, and has been allowed to fill SHRP's cells.

The data from these sites will be stored in the national data base and analyzed along with other SHRP data. Once the data has been compiled and validated, it will be made available to the international research community.

I understand that a presentation regarding this matter is scheduled for the Friday morning "pavement performance" session of this workshop.

For those countries having an ongoing pavement monitoring program, it may be possible to link these programs with SHRP's experiment.

This can be done by selecting a representative subset of their test section network, and by characterizing and monitoring these sections according to SHRP standards in parallel to their normal monitoring program. The result of this effort will allow correlation of the output of the two experiments. (Norway, Sweden, Denmark, and Australia have adopted this approach.)

Another option is to develop a parallel pavement monitoring program designed to fulfill specific objectives and adapted to a specific context.

These programs are somewhat autonomous but are designed to be "SHRP compatible" in order to facilitate information exchange and to provide for the interaction between programs allowing, for example, the use of SHRP standards and facilitating communications between contractors. (France, Netherlands, Finland, United Kingdom, and Canada's C-LTPP program have adopted this approach.)

Canada has a long tradition of cooperation with the United States. The two countries have many similarities and common problems, even though they are quite different in many respects. This makes cooperation very profitable for both countries. SHRP provides an excellent opportunity to strengthen this privileged relationship between two neighbors through Canadian participation in the SHRP program and by complementary research conducted in Canada.

There are two main goals to our participation:

- o To maximize benefits from SHRP research, and
- o To address specific problems by performing complementary research

In addressing these two goals, we have structured our program into four components to maximize the impact of SHRP research on Canadian practice, as follows:

- By monitoring SHRP's research and disseminating its results and information in a number of ways,
- By integral participation in some high interest projects, such as the LTPP and the asphalt technical areas, as well as in the program management, through loaned staff, and
- By implementing a structure to ensure the efficient transfer of SHRP's technology.

In addition, C-SHRP is also complementing SHRP's research through a small scale research program addressing uniquely Canadian needs and problems. The complementary research projects have been grouped to coincide with SHRP's four major research areas.

We have approached involvement in the LTPP technical area in two ways. One involves the inclusion of Canadian sections as an integral part of the SHRP LTPP program, General Pavement Studies (GPS) and Special Pavement Study (SPS) experiments.

So far, 10 SPS sections and 45 GPS sections have been selected as part of the SHRP LTPP program. The 45 GPS sites represent a contribution of approximately 18 percent to the total sites selected in the 23 states closest to the Canadian border which have conditions similar to the southern part of our country.

Most sites are within close proximity of the border, where the vast majority of our population and road networks are located. Therefore, they are readily accessible for regional monitoring.

By adding test sections in Canada, provinces are adding pavement performance information in a marginal, "low data density" zone of the experiment. In addition, Canadian test sections will expand LTPP inference space to Canadian conditions. Canadian participation will give the provinces a higher level of confidence in LTPP results, and will facilitate the application of LTPP products north of the border.

Canada will obviously benefit from the direct contact and exposure to emerging technology, such as the falling weight deflectometer (FWD) and PASCO surface condition survey equipment. This should encourage Canadian agencies to move towards this new technology and facilitate the transition.

The second approach consists of developing a small scale highly focused LTPP program designed on the basis of specific Canadian research needs and scaled to fit our particular requirements. The program is independent, but it has been structured to be compatible and complementary to the U.S.-LTPP experiment.

To support the concept of a Canadian study, an experimental design requiring a minimum of 30 sites, with a minimum of two sections per site, was developed.

The study was designed to strategically overlap with two LTPP experiments: GPS-6 and SPS-5. C-LTPP will expand the experimental conditions of these two studies to include typical northern U.S. and Canadian conditions of:

- Lower traffic
- Lower temperature
- Consideration for frost action and seasonal variations in the mechanical properties of pavements

In summary, due to the wide variety of conditions and limited resources, the Canadian LTPP program is highly focused on specific needs and priorities, incorporating various rehabilitation strategies of AC pavements, with particular consideration of frost action.

It considers lower traffic and temperature environments, including severe frost action and seasonal variation of pavement response.

It encourages the replacement of traditional practices with new and emerging technology, and it will provide an independent data set to allow for validation and calibration of LTPP models.

In conclusion, we believe that international cooperation in highway research has the potential of positive results for all the participants involved.

I hope that this presentation, representing a Canadian perspective, has provided a demonstration of this through the cooperative and complementary programs that have been developed between SHRP and C-SHRP.

The U.S. Strategic Highway Research Program has opened the door of opportunity for international cooperation in highway research. Without question, it has provided the catalyst for Canada to enhance its highway research efforts and to play a small part in this significant and exciting undertaking.

In closing, I would particularly like to thank our C-SHRP coordinator, Greg Williams, and one of our current Canadian loaned staff members, Guy Dorè, for their assistance in putting this presentation together, and to you, ladies and gentlemen, for your attentiveness and patience at the end of a long afternoon.

Thank you.

Session II

THE FUTURE OF LOAD EQUIVALENCY FACTORS

by

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SHRP SUMMER WORKSHOP
August 1-3, 1991

1. INTRODUCTION

This short paper originally was meant to attempt to provide some insight into how SHRP LTPP data could be used to develop "new-improved" load equivalency factors (LEF) for pavement design and analysis purposes. What the paper became was more an overview of the various ways in which LEFs have been estimated in the past. An understanding of past practices hopefully serves us well for the future.

2. BASIC CONCEPT

All pavement design procedures require some estimate of traffic. A common measure of traffic is "equivalent single axle loads" (ESALs). This concept originated from the American Association of State Highway Officials (AASHO) Road Test [1, 2] conducted in the late 1950's and early 1960's in Illinois. Essentially, ESAL's is a number which represents both a measure of the <u>number</u> and <u>magnitude</u> of truck axles expected on a specific pavement structure. Thus, all mixed highway traffic is converted to a single number. Commonly, mixed traffic is converted to the number of 18,000 lb equivalent single axle loads. The magnitude of 18,000 lbs was set in the early 1960's (when the concept was first used) due to this value then being the federal maximum single axle load.

To provide some indication of the size of ESALs for typical highways, the following is provided [after Ref. 3]:

Type of Highway	Range of ESALs*
1. Parking lots, light traffic residential streets	≤7,000
2. Urban and rural minor collector streets and roads	70,000-150,000
3. Light industrial streets and roads	700,000-1,500,000
4. Rural Interstate	2,000,000-4,500,000
5. Urban Interstate	7,000,000-15,000,000

*ESALs for a 20 year period (flexible pavements).

3. ESAL TRENDS

One reason that the various SHAs have been and continue to be concerned about truck and bus traffic is the simple fact that virtually all ESALs are caused by these vehicles (autos and pickups are normally insignificant contributors). In fact, Federal Highway Administration (FHWA) data [4, 5] shows the current trend (Figure 1). This figure shows "typical" ESALs/day growth rates versus "typical" average daily traffic (ADT) for the rural Interstate system. Noteworthy is the observation that as the ADT increased about 120 percent over 16 years (1970-1986), the ESALs/day increased 300 percent during the same period.

Data from the Motor Vehicles Manufacturers Association [6] published in 1983, estimated the following numbers of trucks and buses in the U.S.:

Vehicle	Number
Light trucks Medium trucks and buses Heavy trucks and buses	30,900,000 3,100,000 1,500,000
Total	35,500,000

Light trucks are defined as pickups and vans; medium trucks are city delivery trucks (for example); and heavy trucks are over-the-road tractor-trailer combinations. If we assume that most of the load related pavement damage is done by the medium and heavy trucks and that there are a total of about 175,000,000 automobiles and trucks in the U.S. ([1986 data from Ref. 5], then only 2.6 percent of all vehicles (or about 1 out of every 40 vehicles) is responsible for the majority of the load related pavement damage.

4. ESAL COMPONENTS

When estimating ESALs, the following vehicle load components influence the associated LEFs:

(a) Axle load (or individual tire loads)
(b) Repetitions of axle (or tire) loads
(c) Tire inflation (contact pressure)
(d) Axle and tire configuration
(e) Distribution of traffic across the pavement
(f) Vehicle speed (and associated vehicle dynamics)
(g) Road type, structure and roughness

These factors all contribute to how a pavement structure responds to any vehicle. How much each contributes to LEFs is still a matter of much study (past, current and, undoubtedly, future). In the following subsections, the factors of axle load, load repetitions, and tire pressures will be more fully described.

4.1 AXLE LOADS (TIRELOADS)

The current Interstate federal axle load limits (except for SHAs with exceptions due to "grandfather") rights are [7]:

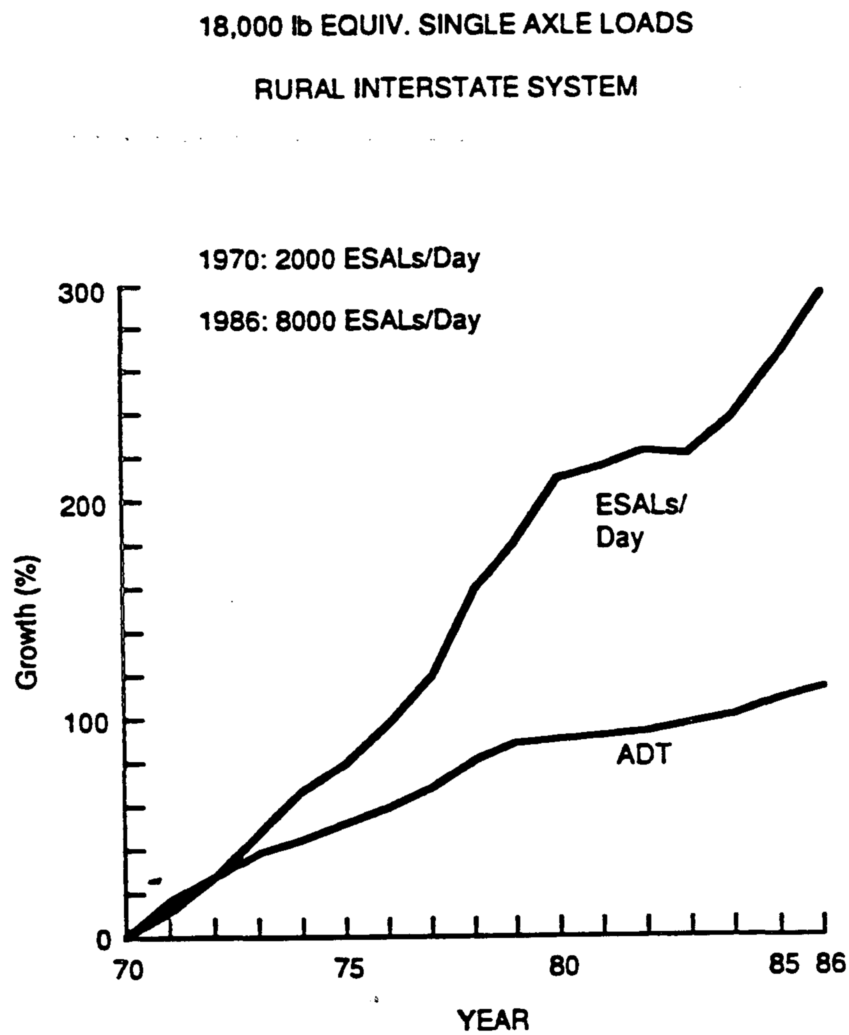

Figure 1. Traffic Trends [after Ref. 5]

(a) Single axles = 20,000 lbs
(b) Tandem axles = 34,000 lbs
(c) Gross vehicle weight = 80,000 lbs.

A single axle weight is the total weight on all wheels whose centers are within 40 inches (longitudinally). A tandem axle is one which has its total weight on two or more consecutive axles whose centers (longitudinally) are spaced more than 40 inches but not more than 96 inches apart.

In addition to maximum axle loads, further restrictions (or allowances) apply to vehicle legal weights based on axle spacings between any group of two or more consecutive axles. This is formally referred to as the "Bridge Formula" [7]. The purpose of the bridge weight formula is to protect highway bridges from being overstressed by specific types of vehicles thus keeping bridge structures within tolerable stress ranges.

Both individual axle load limits and the bridge formula have been revised over the years with the last major revisions made by Congress in 1974. The first AASHO policy statement on weight limits was issued in 1932 which provided for a maximum load of 16,000 lbs on a single axle. Specific weight limits can vary from state-to-state and certainly between countries. For example, the maximum allowable load for a single axle in Sweden is 10 metric tons (about 22,000 lbs).

About half of the SHAs have regulations limiting allowable load per inch width of tire. Based on a slightly dated survey [8], this tire load limitation varies from a high of 800 lbs per inch (New York, etc.) to a low of 450 lbs per inch (Louisiana) with the national average about 640 lbs per inch. Recently, for example, the states of Washington, Oregon and Idaho coordinated their limits and adopted a standard of 600 lbs per inch for all three states. Clearly, this limit can have a significant impact on the use of single tires in lieu of duals on axles (hence LEFs).

4.2 REPETITION OF LOADS

Axle load equivalency has been one of the most widely adopted results of the AASHO Road Test, i.e., to relate relative pavement damage to axle type and weight. A variety of equivalency factors can be used depending on the type of pavement (flexible or rigid), the associated thickness and terminal design conditions (amount of expected pavement distress and roughness at the end of a pavement's initial design life). Most SHAs estimate ESALs over some fixed time period - say 10 to 30 years.

The relationship between repetitions is not arithmetically proportional to the axle loading. For example, a 10,000 lb single axle needs to be applied to a pavement <u>more</u> than 1.8 times the number of repetitions of an 18,000 lb single axle to have the same effect, in fact, about <u>10 times</u>. Similarly, one repetition of a 20,000 lb single axle equals about 10 repetitions of a 20,000 lb tandem axle to have an <u>equivalent</u> effect.

The above stems from AASHTO equivalency factors [9] which are widely used both nationally and internationally by pavement designers. A sample of such equivalency factors are shown in Table 1. Other basic observations can be drawn from such equivalency factors:

(a) A 20,000 lb single axle does over 7,000 times more damage than a 2,000 lb single axle ($1.47 - 0.0002 = 7,350$).
(b) A 30,000 lb single axle does about 5 times more damage than a 20,000 lb single axle ($6.8 - 1.47 \simeq 4.6$).
(c) A 30,000 lb single axle does about 20 times more damage than a 30,000 lb tandem axle ($6.8 - 0.695 \simeq 9.8$).

Table 1. Sample of AASHTO Equivalency Factors for Flexible Pavements [from Ref. 9]

Axle Type	Axle Load (lbs)	ESAL Equivalency (Factor)*
Single Axle	2,000	0.0002
	10,000	0.102
	18,000	1.00
	20,000	1.47
	30,000	6.8
	34,000	11.3
	40,000	22.5
	50,000	60.0
Tandem Axle	2,000	0.0000
	10,000	0.009
	18,000	0.092
	20,000	0.141
	30,000	0.695
	34,000	1.11
	40,000	2.03
	50,000	4.64

*Asphalt concrete thickness approximately 9 inches (SN=4)

Such comparisons can be endless, but the basic point is straightforward in that it is easy to see why SHAs are concerned about:

(a) potential changes (upward) in allowable axle loads,
(b) illegal axle loads, and
(c) improved estimation of LEFs.

4.2.1 FOURTH POWER LAW

Equivalency factors such as those illustrated in the preceding section are often described as confirming to a "fourth power law". This concept was well summarized by Yoder and Witczak [10] and has been confirmed both at the AASHO Road Test and through theoretical and other field studies. Essentially, the relative amount of pavement damage in comparing one axle load to another, increases as function of the fourth power. To illustrate, the relative damage caused by a 30,000 lb single axle when compared to a 20,000 lb single axle according to the fourth power law is:

$$\text{Relative damage} = \left[\frac{30{,}000 \text{ lb}}{20{,}000 \text{ lb}}\right]^4$$

$$(1.5)^4 \simeq 5.1$$

Using AASHTO equivalency factors from Table 1, this value was 4.6. Thus, both calculations are in approximate agreement.

4.3 TIRE PRESSURES

Although different levels of tire pressure (contact pressure) are not commonly used in calculating equivalency factors, it is clear that for some pavement types, higher truck tire inflation pressures can significantly impact pavement performance. Concern about this specific issue was the subject of an AASHTO sponsored workshop held in Austin, Texas, during February 1987 [11]. Further, the effect of tire pressure and tire loads is currently under study by the Federal Highway Administration (FHWA) [12].

4.3.1 TIRE PRESSURES AT AASHO ROAD TEST

Highway Research Board Special Report No. 73, "The AASHO Road Test - Proceedings of a Conference - May 16-18, 1986 - St. Louis, MO" is an excellent reference which can be used to review various truck tire pressure issues investigated at the Road Test. From this document, the author has selected two papers for review [13, 14].

The paper by Kent [13] showed that the average "hot-tire" air inflation pressures were about 11 psi higher than the "cold-tire" air inflation pressures. These tires were on either 18,000 or 22,400 lb single axles (i.e., 4,500 lb or 5,600 lb per tire). The increase in air inflation pressure ranged from 9 tp 20 psi for these two axles. The tire pressure increase generally stabilized after 1.5 hours of running on the test pavements. The recommended Tire and Rim Association cold air inflation pressures were about 75 psi for these tires (10.00 x 20 tires for 18,000 lb single axle and 11.00 x 20 tires for 22,400 lb single axle).

and untreated aggregate bases at the Road Test. Of interest is the observation that the bituminous treated bases (with 14.5 inches total thickness of surfacing and base) experienced about 0.42 inch of rutting after 1,000,000 repetitions (unweighted) of the 48,000 lb tandem axle (6,000 lb tire load). Given that these tires had running (hot) air inflation pressures of about 85 to 90 psi and the axle loads in terms of 18,000 ESALs were about 9,000,000 (30,000 lb single axle) and 4,800,000 (48,000 lb tandem axle), then similar trafficked roads (and construction) which are experiencing say 0.4 to 0.7 inch ruts are doing nothing more or less than the pavements at the Road Test.

The rutting reported from the Road Test appears to be similar to values from the Brampton, St. Anne and San Diego Road Tests, as summarized by Haas and Hudson [15]. At the Brampton Road Test for a 11.5 inch thick asphalt concrete pavement, the reported rut depth at about 5,000,000 ESALs was 0.5 inch. For the St. Anne test for a 10 inch thick asphalt concrete section at about 2,000,000 ESALs, the rut depths were about 0.5 to 0.6 inch. At the San Diego Road Test for a 14.6 inch asphalt concrete/asphalt treated base pavement, the reported rut depth was between 0.4 to 0.5 inch at about 1,700,000 ESALs.

Thus, if SHAs and/or the SHRP GPS sites are experiencing rut depths in a range much larger than 0.5 to 0.6 inch for heavy traffic, then loading conditions may have changed. Further, if SHAs are measuring "hot" inflation pressures in the range of 95 to 105 psi, then this translates to "cold" inflation pressures of about 85 to 95 psi (pressures which are 10 to 20 psi higher than those for the heavier vehicles at the AASHO Road Test).

4.3.2 TIRE PRESSURE SURVEYS

Brown [16] noted that several states have measured "hot" tire inflation pressures in recent studies. The results were generally similar in that the average was about 105 to 110 psi. Clearly, hot tire inflation pressures are now about 20 psi higher than those measured at the AASHO Road Test. Since the results of the AASHO Road Test have been widely used in pavement design, this changed condition is of concern to the SHAs (and the potential for even higher inflation pressures).

Unpublished survey data provided to the author by the Owner Operator - Independent Drivers Association of America (Oak Grove, Missouri) during March 1987 resulted in the following:

- Steering axles
  - (a) 90 percent use radial ply tires
  - (b) 10 percent use bias ply tires
  - (c) Inflation pressures
    - (i) Average: 101 psi
    - (ii) Minimum: 80 psi (1 percent of survey)
    - (iii) Maximum: 120 psi (2 percent of survey)
- Drive axles
  - (a) 92 percent use radial ply tires
  - (b) 8 percent use bias ply tires
  - (c) Inflation pressures
    - (i) Average: 99 psi
    - (ii) Minimum: 80 psi (2 percent of survey)
    - (iii) Maximum: 120 psi (1 percent of survey)
- Trailer axles
  - (a) 87 percent use radial ply tires
  - (b) 13 percent use bias ply tires

(c) **Inflation pressures**
(i) **Average:** 97 psi
(ii) **Minimum:** 80 psi (3 percent of survey)
(iii) **Maximum:** 120 psi (1 percent of survey)

The above survey results were based on several hundred responses to a questionnaire. The question of whether the tire inflation pressures were measured "hot" or "cold" was not asked, thus the results probably represent a bit both.

5. MODELING LEFs

Given the introductory and background information, we will now briefly describe how LEFs can be estimated. These approaches include:

(a) Performance based
  (i) Serviceability
  (ii) Distress

(b) Response based
  (i) Deflections
  (ii) Strains
    •Modeled
    •Field measurements

Examples of each kind of LEF approach will follow.

5.1 PERFORMANCE BASED LEFs

5.1.1 SERVICEABILITY LEF

The serviceability approach is used to estimate flexible pavement LEFs. These specific LEFs are calculated from the following equation:

$$\frac{W_x}{W_{18}} = \left[\frac{18+1}{L_x+L_2}\right]^{4.79} \left[\frac{10^{G/\beta_x}}{10^{G/\beta_{18}}}\right] [L_2]^{4.33} \qquad \text{Eq. 1}$$

where

$\frac{W_x}{W_{18}}$ = inverse of LEF

G = log (4.2-p_t/4.2-1.5) = servicability loss ratio

p_t = terminal serviceability index

SN = structural number

$$\beta = 0.4 + \frac{0.081\ (L_X+L_2)3.23}{(SN+1)5.19\ \ L_2\ 3.23} = \text{performance curve shape}$$

L_x = axle load
L_2 = axle code
1 = single
2 = tandem
3 = tridem (added 1986)

An example of the use of Equation 1 follows:

Calculate the LEF for a 30,000 lb single axle for a SN = 3 flexible pavement using a p_t = 2.5

Calculations

$L_x = 30$
$L_2 = 1$

$$G = \log \frac{(4.2 - 2.5)}{(4.2 - 1.5)} = -0.2009$$

$\beta_x = 4.388$
$\beta_{18} = 1.2204$

$$\frac{W_{30}}{W_{18}} = \left[\frac{18+1}{30+1}\right]^{4.79} \left[\frac{10^{-0.0458}}{10^{-0.1646}}\right] [1]^{4.33} = 0.1260$$

$$\frac{W_{30}}{W_{18}} = 12.6\ \%\ \text{of}\ W_{18}\ \text{loads allowable with a}\ W_{30}\ \text{single axle load}$$

LEF $= 1/0.126 \simeq 7.9$

5.2 RESPONSE BASED LEF

A good example of response based LEFs is the Roads and Transportation Association of Canada (RTAC) study on Canadian vehicle weights and dimensions. RTAC calculated LEFs using both the deflection and strain based approaches [17].

RTAC measured during the summer of 1985, pavement surface deflections and asphalt concrete (AC) tensile strains under a range of truck axle loads and configurations. These measurements were made at 14 instrumented test sites across Canadá. The axle loads ranged from 20,000 lb to 24,000 lb on single axles, 12,000 lb to 49,000 lb on tandem axles and 44,000 lb to 71,000 lb on tridem axles.

5.2.1 DEFLECTION LEF

RTAC defined a LEF as the number of applciations (N_b) of a standard (or base load) which are equivalent in destructive effect to one application (N) of a given load (LEF = N_b/N). The calculation of deflection LEFs assumes that a limiting relationship between surface deflection and traffic loadings exists in the form

$$N = k\,(1/D)^c \qquad \text{Eq. 2}$$

where

N = axle applications,
D = surface deflection, and
k_1c = regression constants.

Combining Equation 2 with LEF = N_b/N results in:

$$\text{Single Axle LEF} = (D/D_b)^C \qquad \text{Eq. 3}$$

where

D/D_b = ratio of surface deflections caused by a single axle load to those recorded under a standard (18,000 lb) single axle-dual tire load, and
c = slope of the deflection - traffic loading relationship.

The RTAC equation used to estimate deflection based LEFs for tandem or tridem axles was:

$$\text{LEF} = (D_1/D_b)^C + \sum_{i=1}^{n-1} (\Delta_i/D_b)^C \qquad \text{Eq. 4}$$

where

D_1/D_b = ratio of maximum surface deflection under leading axle (of the group) to standard axle deflection,

Δ/D_b = ratio of differences (between maximum deflection under each succeeding axle and the minimum residual deflection preceding the axle) to the standard axle deflection (refer to Figure 2).

n = number of axles in groups and

5.2.2 STRAIN LEF

The RTAC calculation of strain based LEFs used the following equation:

$$\text{LEF} = \sum_{i=1}^{n} (S_i/S_b)^C$$

where

S_i/S_b = ratio of longitudinal tensile strain recorded under each axle to those under standard axle (refer to Figure 3)
n = number of axles in group, and
C = slope of fatigue life - tensile strain relationship (used $C = 3.8$).

5.2.3 CALCULATED PAVEMENT RESPONSE LEFS

A modeling technique commonly used in flexible pavement analysis is the layered elastic approach. This approach (as well as finite element approaches) can be used to combine

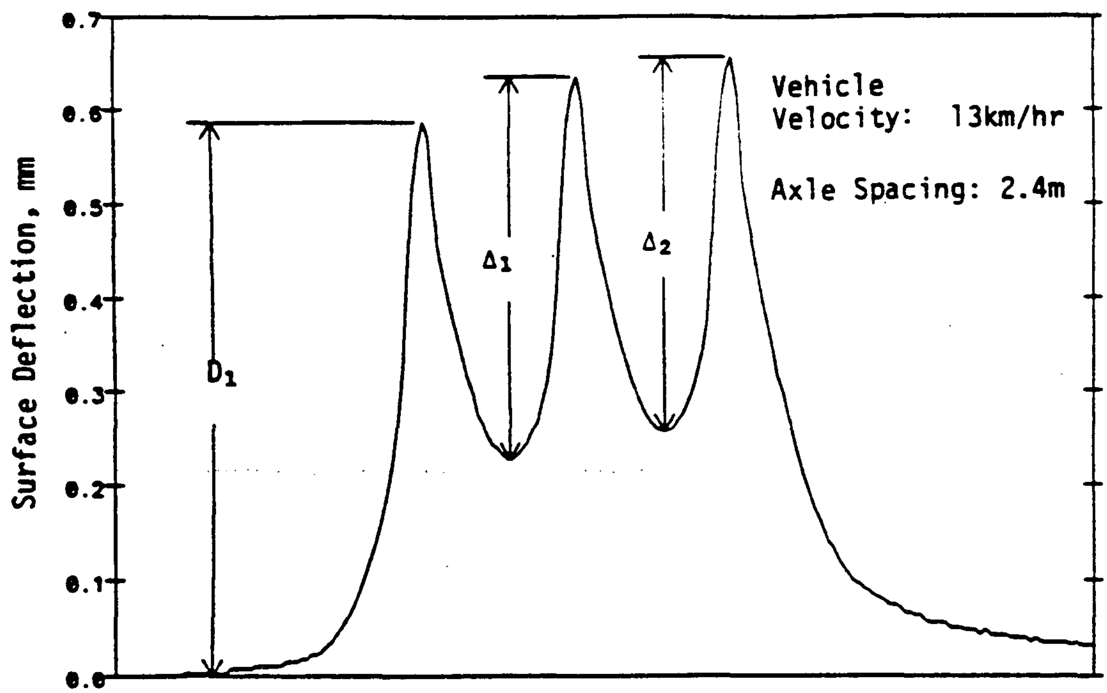

Figure 2. Surface Deflection Profile - Tridem Axle [from Ref. 17]

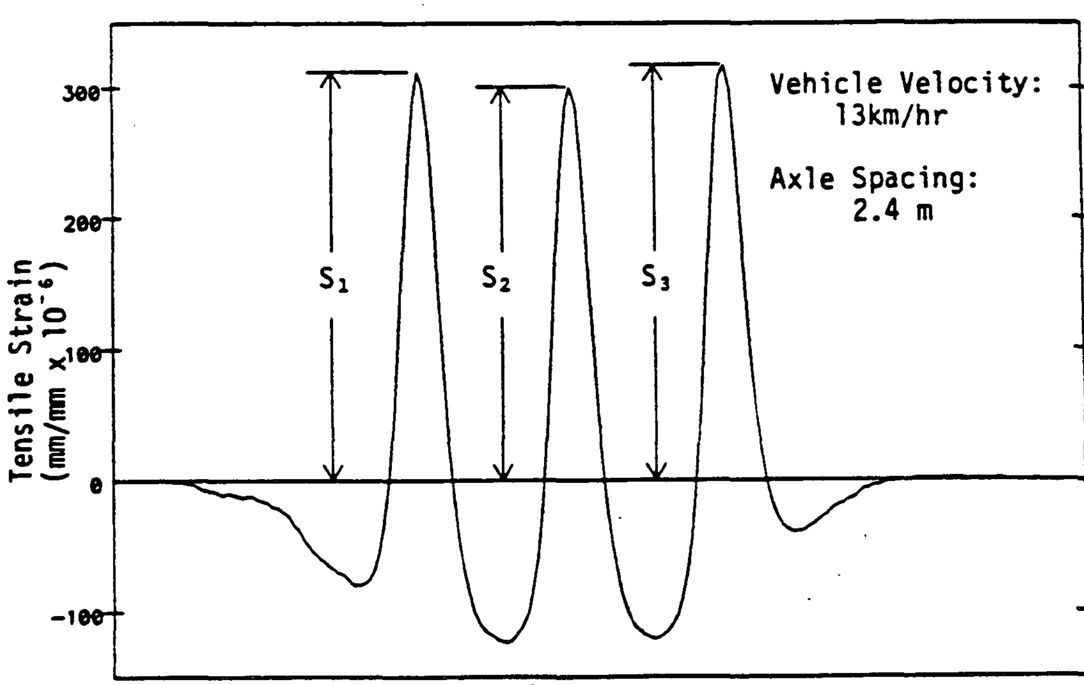

Figure 3. Tensile Strain Profile - Tridem Axle [from Ref. 17]

the subgrade soils) to estimate pavement life in terms of axle repetitions and hence calculate load equivalencies. Such equivalencies are only approximate but provide some insight into combined load effects.

Load equivalencies can be calculated from these results by use of the following:

$$LEF = \frac{[Nf]_{18}}{[Nf]_i}$$

where

$(N_f)_{18}$ = loads to failure for an 18,000 lb single axle load with dual tires with a tire pressure of 80 psi (for example),
$(N_f)_i$ = loads to failure for a specific axle (or any other standard condition) with a specific tire configuration, load and tire pressure.

6.0 CONCLUDING REMARKS

Given the ever so brief background on some of the ways LEFs have been calculated (estimated) in past efforts, it is reasonable to assume that SHRP LTPP data will be used in similar schemes. However, there will be a significant difficulty in dealing with the mixed traffic loadings for both the GPS and SPS sites. A few, final recommendations are offered:

To the "SHRP Program":

(a) Complete the SPS-1 and SPS-2 (Structural Factors) test sites and instrument some of the sections to provide for load response measurements.

(b) Increase the SHRP LTPP emphasis on pavement seasonal effects (material parameters are important for some LEF calculation schemes).

(c) Emphasize the development of improved pavement failure criteria from the LTPP effort (can be of direct value in estimating LEFs).

(d) The SHRP contractor(s) which model (estimate) LEFs must be aware of past LEF efforts and their associated pros and cons.

To the "Pavement Community":

(a) Work with the trucking industry to better understand the major structural user of the nation's highways. This includes truck systems and components.

(b) Continue to improve our traffic monitoring capability.

(c) Recognize what the real problems are (traffic monitoring vs. LEFs for example).

The bottom line, as this author sees it, is that we <u>must</u> continue to improve our understanding of pavements and vehicles (and their interaction) first. Then, the

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ENVIRONMENTAL FACTORS IN LONG TERM PERFORMANCE

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ENVIRONMENTAL FACTORS IN LONG TERM PERFORMANCE

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CONFERENCE OBJECTIVES

The LTPP session within the SHRP Mid Program Meeting has two very important functions. They are to (a) provide a concentrated focus upon the current LTPP data collection/analysis process to date, and (b) assess what, if any, mid-course corrections are required to improve the benefits gained from the SHRP-LTPP study.

As noted within the title of this paper, the major emphasis is placed upon only one element of the overall LTPP system. This element is the environmental aspect of the LTPP program. As such, both the near term potential and long term potential of the LTPP program are examined. In terms of this paper, "near term" refers to the potential use of data accumulated to date, while "long term" refers to data accumulated in the remaining years of SHRP and beyond.

KEY CONCEPTS OF 1986 AASHTO DESIGN GUIDE

Without question, one of the major objectives of the LTPP program is to provide data and analysis of pavement performance that will serve as the primary source of future revisions to the AASHTO Design Guide. In order to fully appreciate the potential for these changes, it is important to review several concepts of the current AASHTO Design Guide.

One of the more important factors to understand concerning the AASHTO Guide is that it uses a performance time model based upon "functional" deterioration. The performance variable is expressed by the PSI (PSR) "Present Serviceability Index" which is a unique numeric value expressing the "collective" impact of all types of pavement distress in assessing how well the pavement is serving its intended function of providing a safe, smooth and economically efficient riding surface. While various mechanistic/theoretical models may be used to help explain the performance model, the AASHTO Design approach is still "heavily empirically" oriented in that it is based upon the experience and subjective user opinion of performance and failure threshold levels. The current 1986 version does not have any specific pavement distress predictive capability within the design/analysis model.

While the above clearly sets out some of the major limitations of the current (1986) Design Guide, it should be noted that very significant improvements were made in the 1986 Guide towards a more rational framework for assessing pavement performance.

Table 1 is a summary of the 14 major changes that were incorporated into the 1986 Design Guide. While the reader is referred to the AASHTO Guide for details of these changes, the author has indicated those changes that are related (directly or indirectly) to the major objective of this paper, i.e., the environmental influence upon pavement performance. As can be

Table 1

Major Changes in 1986 AASHTO Design Guide

Major Area	Presence of Environmental Effect
* Soil Support Value	Yes
* Layer Coefficients	Yes
* Drainage Considerations	Yes
* Environmental PSI Loss	Yes
* Tied Shoulders/Widened Lanes	Yes
* Subbase Erosion	Yes
* Mechanistic Empirical Design Framework	Yes
Reliability	No
Life Cycle Cost Methodology	No
Rehabilitation	No
Pavement Management	No
Load Equivalency Values	No
Traffic	No
Low Volume Roads	No

* Denotes factors of direct major concern to paper

noted, seven (7) of the 14 major changes have strong environmental impacts.

While several of these factors may not easily be viewed as being related to environment, the reader should understand that pavement performance is driven by two separate "environmental manifestations." They are:

1. External Pavement Environment
2. Internal Pavement Environment

The external climatic conditions at a given pavement site are responsible for many types of "non-load" associated pavement distress mechanisms (e.g., aging of asphaltic mixtures, frost heave, joint blow ups, etc.). These distresses are directly influenced by the range and magnitude of the temperature and precipitation cycles occurring over the life of the pavement. On the other hand, the "internal pavement environment" plays the most significant role in defining the changes in material layer response (e.g., modulus) over time. Thus, thermal and moisture changes due to the interaction of external climate, layer material drainability properties and ground water table locations are directly responsible for the magnitude and time pavement layer materials are subjected to certain levels of stress/strain/deformation due to the applied wheel loads imposed on the pavement system. These factors in turn are the primary mechanisms for the development of the major load associated pavement distress mechanisms (e.g., cracking and permanent deformation).

Using this broad concept of "environmental influence" it is possible to describe in more specific detail the environmental changes incorporated into the 1986 Guide.

1. Regional Factor Replaced by Resilient Modulus: One of the most significant changes to occur was the introduction of the resilient modulus in lieu of the empirical soil support value. In addition, the M_r value of unbound granular subbase/base materials was introduced and general correlations developed between moduli and layer coefficients. The direct influence of drainability by the "m_i" coefficient applied to the layer coefficient also was significant in that it clearly demonstrated that moisture (degree of saturation) and the time the material exists at a given moisture are important in defining the overall "typical" or "effective" modulus of all pavement layers.

2. "Effective" Design M_r Analysis: The introduction of an "effective" modulus for design was a significant improvement to state of the art. By definition, an "effective" material/pavement response is a unique value of the response (i.e., M_r) that yields the same expected performance/design life as one obtained by cumulative annual damage concepts using time dependent variations of the response parameter. Thus, the introduction of the "effective" M_r (k_c) parameter provided a design methodology, using cumulative damage principles, that allowed for seasonal, time dependent changes in material response to be accounted for. Unfortunately, while the methodology was presented, no guidance was given to the engineer as to how to select the time dependent response changes. This was directly due to the very poor state of

the art in this area.

3. Environmental PSI Loss: For the first time, the recognition of PSI losses due to "external environmental" factors was made in the 1986 Guide. The concept of total PSI loss (at a given time) due to losses in both structural load and external environmentally inducted distresses (i.e., frost heave and high volume change) was a direct step towards expanding the philosophy that not all deterioration is due to load.

4. Specific Thermal/Environmental Design Factors: Significant design methodology improvements were made in the rigid pavement portion of the Design Guide. In addition to load induced stress analysis of slabs, several subtle, but significant, improvements relative to the direct use of various environmental parameters were made. Such factors as: (a) design temperature drop, (b) thermal coefficient ratio (concrete to steel), (c) joint opening for sealant analysis and temperature influence upon the load transfer coefficient all required the designer to account for specific environmental conditions for the site in question.

5. Framework for Mechanistic-Theoretical Design: The introduction of Part IV to the Design Guide dealing with a framework for a more mechanistic design methodology is viewed as a major environmental consideration simply due to the fact that it represents the only way in which the rational influence of the total environment upon design/performance will eventually be accounted for in a rational manner.

In summary, the 1986 AASHTO Design Guide presented the first order methodology for assessing the influence of both "external and internal" environmental impacts upon design and performance. While this "framework" was set in place, the most severe limitation of the 1986 Design Guide is that no guidance is presented (due to our current lack of knowledge) as to how the engineer can accurately assess and input information concerning the real-time prediction of material response as a function of:

1. External Climatic Regime
2. Material/Layer Properties
3. Ground Water Regime

over the expected life of the pavement system.

OVERVIEW OF THE LTPP-GPS

The GPS portion of the SHRP-LTPP area is intended to provide the major source of pavement performance data which will be available for the first analysis studies within the five year SHRP program. It is envisioned that this information will be used by both major SHRP analysis contractors in the P-020 and A-005 areas. Because other papers are the subject of the detailed planning behind the GPS as well as SPS studies, only a brief overview of the GPS is presented, with emphasis placed on the major data being collected.

While each GPS experiment has been specifically designed to account for the potential of major variables within the statistical cell matrix, all of them have the following four major considerations:

1. Climatic Region
2. Soil Subgrade
3. Pavement Structure
4. Traffic

Of specific importance to this paper is the fact that the "Climatic Region" variable has been based upon various combinations of rainfall and temperature occurring within the United States (e.g., wet-freeze).

A wide variety of pavement related data is being collected and evaluated. For each GPS section, a list of inventory data related to location, age, construction history, pavement cross section, has been collected. In addition, field cores/borings and test pits (usually two per GPS section outside the existing section limits) will provide the eventual basis for direct laboratory testing of the various layer material properties.

Most important is the Monitoring portion of the data. Included in this category will be periodic measurements (or estimates) of the five factors noted below:

1. Profile Measurements
2. Distress Measurements
3. NDT Structural Response (FWD) Measurements
4. Traffic
5. Climatic

Items 1 through 3 are currently being collected on all GPS sites. Traffic data will come from a large variety/range of information sources. As such, several hierarchical levels of traffic reliability will be available. On some GPS sections, only estimates of 18 kip SAL repetitions will be available, while other GPS sections will eventually be equipped with WIM (weigh in motion) equipment to provide the best possible estimate of equivalent traffic repetitions. Finally, it is important to note that no information has been collected to date concerning climatic data for any GPS sites. A plan is now being developed to determine the details regarding external climatic variables to be obtained and the frequency of the data collection process for GPS site inclusion into the national pavement data base.

Finally, one important factor relative to the eventual analysis of environmental consequences upon the LTPP sites is that "linkage" was established between the FWD testing and the test pit/drilling activity for the GPS sites. In general, the materials from the test pit locations were obtained during the same day (and same location) as the FWD testing. This "linkage" should therefore afford studies assessing the environmental conditions (internal) of the pavement system to the overall measured deflection response for each GPS site for the specific day in which the GPS testing was accomplished.

NEAR TERM EXPECTATIONS (LTPP ENVIRONMENTAL STUDIES)

The material presented up to this point was intended to provide salient background information regarding key environmental emphasis on the LTPP study. In order to assess limitations (real or perceived) and then consider possible mid-term corrections to the LTPP data effort, it is necessary to speculate on what potential "Near Term" results may be anticipated from the current GPS data collected to date. What follows is obviously the opinion of the author and it should be recognized that the final success of this effort will lie with the ingenuity of the P-020 and A-005 contractors.

While details of the analysis to be conducted within the remaining SHRP period by the P-020 and A-005 contractors still remains to be developed, it is probably a fair assessment to state that the P-020 contractor will rely more upon empirical-statistical regression oriented studies. In contrast, the current thinking of the A-005 contractor is to utilize a more mechanistic or theoretical approach in the analysis (for asphaltic pavements).

It is felt that the "Near Term" changes in the state of the art will initially evolve from the P-020 study, particularly with the potential impact of these results upon future AASHTO Design Guide revisions. From an environmental perspective, it is postulated that several major advances <u>may potentially</u> be accomplished. They are:

1. Performance models incorporating the empirical influence of climatic regions and/or specific external climatic variables <u>may be developed</u> from the initial round of the GPS analyses.

2. Global distress prediction models incorporating both load and environmental variables <u>may be developed</u> for a wide category of

pavement types.

If these two major objectives can be obtained, it is obviou that more accurate design procedures will be the major benefit t the profession. A secondary but equally important use of thes results will be the ability to ascertain more accurately th sensitivity of environment and load variables upon future cos allocation studies.

Ideally, while the above objectives may be attainable from th SHRP analysis; the author forseen a major potential problem wit the existing LTPP-GPS data that may cause a serious impact upon th ability to accurately and successfully obtain these major researc goals. This potential major problem is related to the lack o accurate traffic data and, most importantly, the lack of accurat pavement material response data (M_r) to characterize th "effective" response of the subgrade soils. It must be recognize that this inaccurate (large deviations from the truth) data ma lead to very large errors in any statistical performance regressio equations developed. If this does occur, it will undoubtedl confound/hide out ability to accurately indicate the influence o environmental regime upon performance.

On a more positive note, it is apparent that a significan advance may be obtained in the improvement of mechanistic theoretical pavement response modelling. This potential i possible primarily through the fact that "linkage" between the FW testing and coring/boring to obtain representative materials wa conducted. Some of the major items that can be studied with th existing SHRP data are:

1. Comparison of laboratory determined M_r data to M_r values backcalculated from FWD deflection basic measurements.

2. Improved knowledge of lab M_r test procedures and model (non linear) forms for proper interpretation and implementation into theory.

3. Improve theoretical models used for the prediction of stress, strain and displacement.

While data is currently being collected which would allow for the above analysis it is equally important to note that these investigations are not within any SHRP contract work scopes at present. This study will obviously need to be accomplished by non SHRP research activity.

CURRENT LTPP ENVIRONMENTAL LIMITATIONS

In the opinion of the author, there presently exists one major environmentally oriented limitation with the current LTPP data being collected. In general, the SHRP Regional Coordination Offices have essentially completed one round of FWD deflection testing on all known GPS sites. However, it is crucial for the reader to clearly understand that the time (day) of testing a specific GPS site was predicated upon equipment scheduling for the drilling/materials collection phase. As a consequence, no thought was given at all to conducting FWD testing during a "critical" environmental response. Because of this, the FWD testing (and any subsequent attempts to backcalculate material layer properties) must be viewed as a single random point in time rather than conveying any notion that the values/response are "typical or effective" values that are truly representative of design conditions.

One additional complicating factor that is now also coming to light from preliminary computer analysis of the FWD section uniformity is the fact that a significant number of GPS sections may actually be comprised of one or more structural/subsections (i.e., differing cross sections, material type/response, etc.). Also, preliminary analysis is likewise showing that test pit areas may <u>not</u> always be representative of the overall GPS section response. The true impact of these variances that are being determined cannot accurately be assessed at the present time relative to the problems they may cause in the overall performance analysis.

In summary, the current limitations with the LTPP data collected to date are:

1. There is an absolute lack of data to determine what the "effective or design" modulus value of the section subgrade soil, subbase (unbound) and base materials are for performance analysis.

2. Little to no improvements can be made to the state of the art relative to structural layer coefficients (a_i) as well as drainage coefficients (m_i) within the AASHTO design guide framework.

3. Little to no guidance will be available to the engineer

in selecting the appropriate material response value for design/analysis/rehabilitation techniques. This is certainly true for near term research studies and true for long term studies as well, unless major changes are initiated in the remaining FWD data collection plan.

LONG TERM ENVIRONMENTAL NEEDS

It is the author's strong opinion that the "last frontier" of pavement performance modeling that needs to be addressed deals with the environmental issue. In order to eventually possess accurate performance prediction models, engineers <u>must</u> be able to quantify the real time effects of the pavement moisture-thermal regime upon the real time response of all materials present in the system at a given site with known ground water conditions.

It is a fundamental fact that material response (i.e., M_r) is a function of many variables such as type of material; climatic conditions, pavement cross sections, and ground water conditions. Furthermore, because of variable time dependent changes in the external and internal pavement environments, the response (M_r) of all materials change significantly with time.

What is therefore needed is a complete methodology that will allow the engineer to accurately model the anticipated layer response over time. While this concept is extremely important in areas affected by seasonal frost action, it should be recognized that this problem is equally as important in non frost areas as well. The problem is clearly driven by <u>moisture</u> fluctuations in the pavement system.

Finally another environmentally related problem that needs to be addressed more specifically concerns the real time effects of traffic and temperature upon rigid pavement response. Specifically, the concept and analysis dealing with in-situ load transfer of jointed rigid pavements needs significant improvement in the state of the art. A strong need exists to clearly understand the influence of both daily and seasonal thermal changes upon load transfer. Such information is deemed vital if the profession is to ever make sense of data collected by NDT deflection devices to assess in-situ load transfer capabilities of rigid pavement systems. Gradual deterioration of the load transfer capability with time (and/or) traffic repetitions must also be evaluated.

In summary, the two key issues noted (real time material behavior response and real time load transfer) represent the author's opinion as to the critical environmental issues that should be addressed in the future remaining SHRP-LTPP activity. Because these issues have not been addressed to date in SHRP, it is recognized that "mid-course" corrections must be accomplished in the SHRP-LTPP programs as soon as practical.

FUTURE SHRP FWD PLANS

The major environmental needs previously described in this paper must rely heavily (though not solely) upon data collected from FWD equipment. For the remainder of the SHRP study program, it is envisioned that SHRP FWD devices will be used in two key study areas:

1. Evaluations of SPS test sections as they are constructed.

2. Evaluation of the seasonal (environmental) influence upon GPS section deflection response.

At present, it is forecasted that FWD scheduling and availability difficulties may occur in order to realize both study objectives. In order to alleviate this problem, SHRP is now in the process of developing an absolute load/deflection calibration methodology that will eventually be placed within several FWD Regional Deflection Calibration Centers throughout the United States. Once established, and operational, these centers could perform absolute calibration checks on various state DOT and private deflection units in order that they would conform to SHRP standards. This would significantly increase the availability of the number of deflection units available to assist in these two study areas.

At present, detailed operational manuals are being developed by SHRP for each specific SPS category in a prioritized manner reflecting the sequence in which the sections are to be initiated. The second study area, involving the FWD units to assess the seasonal deflection response, is also in the planning stage at the current time.

The present thinking relative to the seasonal plan is summarized below. The major concepts of the study plan are as follows:

1. Study will utilize 10-20% of the current GPS sites.

2. FWD testing will be conducted at each site approximately 10-15 times per year.

3. Sites selected will be within a small radius or "cluster" (from a geographic viewpoint) as possible to minimize travel time and costs.

4. All geographic (Environmental regimes) of the United States will be evaluated.

5. In contrast to current GPS-FWD operational guidelines, the number of test locations within a site will be more limited; testing at a given site may occur 5-10 times per day and only necessary test types will be used (i.e., mid lane basin and joint load transfer).

It is also hoped that a significant percentage of these special sections may also have environmental instrumentation (both external and internal) installed to monitor thermal moisture regimes within and outside the pavement section. In addition to FWD deflection responses, some considerations should also be given to employing Dynamic Cone Penetrometers to determine in-situ changes in material behavior with depth.

Finally it is also hoped that future research would allow for conducting special lab testing on pavement layer materials within each of these instrumented sites to assess newly developed special environmental-material property evaluation tests such as:

1. Moisture - suction (tension)

2. Moisture - hydraulic conductivity

3. Special Frost tests

   a. Frost Susceptibility

   b. Unfrozen Moisture - Subfreezing temperature

   c. Modulus temperature - moisture (frozen and thawed states).

If implemented in accordance with the above noted concepts, the above plan will provide a wealth of important information on the real time material response of pavements under environmental influences. Most importantly the data collected would serve as the basis for verification and/or modification of the newly developed FHWA climatic model developed by researchers at Texas A&M, the University of Illinois and USACE-CRREL. The successful completion of such a study would, in itself, open the "last frontier" of pavement performance modelling.

SUMMARY

This paper has presented an assessment of the major environmental factors within the Long Term Pavement Performance program of SHRP. With the current data collected to date, it is the opinion of the author that

1. Possible advances in expanding performance prediction regression equations to account for environmental conditions (through climatic regions) may be made. However, it is also

suggested that extreme limitations relative to the accuracy of knowing the "design or effective" traffic and layer material response, (particularly for the subgrade) will seriously enhance the difficulties in developing accurate and reliable environmentally based performance production equations.

2. Advances are possible, with the current SHRP FWD - Material data on the GPS sections, to improve our ability to accurately model pavement response (stress strains and displacements). Future lab M_r testing on GPS samples coupled with deflection basin test results are important elements in completing this study.

When the current limitations of the environmental data being collected are critically reviewed, it is apparent that the major weakness lies with a complete absence of data relative to the real time variations in material behavior and response for all GPS/SPS sections. In order to change the direction of this deficiency, it is important that a seasonal FWD plan be developed and implemented as quickly as practical. If this is accomplished, major advances in mechanistic design and analysis are very possible. This should lead the profession to develop an accurate methodology to truly assess the time dependent response of material behavior and subsequently lead to prediction models that yield the most accurate way of assessing future performance for both new and rehabilitated pavement systems.

LTPP DATA ANALYSES:
IMPACTS ON PAVEMENT DESIGN

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INTRODUCTION

The stated LTPP Goals are:

"To increase pavement life by investigation of various designs of pavement structures and rehabilitated pavement structures, using different materials and under different loads, environments, subgrade soil, and maintenance practices."

LTPP objectives are to:

1. Evaluate existing design methods.
2. Develop improved design methodologies and strategies for the rehabilitation of existing pavements.
3. Develop improved design equations for new and reconstructed pavements.
4. Determine the effects of 1) loading, 2) environment, 3) material properties and variability, 4) construction quality, and 5) maintenance levels on pavement distress and performance.
5. Determine the effects of specific design features on pavement performance.

6. Establish a national long-term data base to support SHRP objectives and future needs.

The focus of this paper is to consider some of the potential impacts of LTPP data analysis activities on pavement design.

HISTORICAL PERSPECTIVES

The AASHO Road Test, conducted from 1958 - 1960, at Ottawa, Illinois provided the design concepts and philosophies included in the AASHO Guide (past and current versions). The PSI (present serviceability index) concept was developed in conjunction with the AASHO Road Test activities. The PSI equations (1) are :

$$\text{Flexible: } PSI = 5.03 - 1.91 \text{ Log } (1+SV) - 0.01\,(C+P)^{0.5} - 1.38\,RD^2$$

$$\text{Rigid: } PSI = 5.41 - 1.8 \text{ Log}(1+SV) - 0.09\,(C+P)^{0.5}$$

Where:

SV - Slope Variance

RD - Rut Depth: in inches (both wheel tracks) measured with a 4-foot straightedge

C - Cracking: lineal feet of cracking per 1000 ft^2 area

P - Patching: bituminous patching in ft^2 per 1000 ft^2 area

In the analysis of the Road Test data (1), "serviceability loss prediction equations" were developed for flexible and rigid pavements The development was based on comprehensive statistical analyses of the flexible and rigid pavement data bases.

The "Structural Number (SN)" was utilized to quantify the "structural capacity" of flexible pavements. The SN relation is:

$$SN = a_1D_1 + a_2D_2 + a_3D_3$$

Where:

a_1, a_2, and a_3 are material "Layer Coefficients"

D - Layer thickness, inches

For rigid pavements, working stress in the concrete was selected for use in the serviceability loss equation. The original AASHO Guide equation was extrapolated beyond the Road Test conditions by using the Spangler equation and a "j" factor for considering load transfer.

Three versions of the AASHO / AASHTO Guide (1972, 1981, and 1986) have been published. The original "AASHO Performance Prediction Equations" have been retained in all versions. In the development of the latest revision (1986), a very significant issue was considered. The issue was whether to retain the original "performance prediction equations" procedure or change to "Mechanistic-Empirical (M-E)" concepts and procedures for developing the 1986 Guide.

Relevant to this issue is the fact that the original analyses (1) of the AASHO flexible data base indicated the 1959 Spring normal Benkelman Beam deflection - pavement performance relations (see Figure 1) were approximately "as good as" the SN based performance equation. Thus, the basic premise of M-E design was supported by the original AASHO data bases and subsequent analyses. The decision by the AASHTO Joint Task Force on Pavements was to retain the original "performance prediction equations" for the 1986 AASHTO Guide.

Major changes and modifications were introduced in the 1986 Guide. They included the following topics:

Reliability*, Resilient modulus for soil support*,
Layer coefficient - modulus relations*, Drainage*,
Environment*, Tied shoulders and widened lanes*,
Subbase erosion*, Life-cycle costs, Rehabilitation,
Pavement management, Load equivalency values*,
Traffic*, Low-volume roads

(* Of major interest in this paper)

LTPP PROGRAM

This paper focusses on the potential utilization of the LTPP data base for the original pavements included in the GPS Sections in considering "IMPACTS ON PAVEMENT DESIGN." The orientation is toward "new" or "reconstructed" pavements, not "rehabilitated" pavements.

THE GPS SECTIONS

The five GPS Pavement Types (see Elkins' Denver SHRP Conference paper for details) of interest are:

Pavement Type	# of Sections
GPS-1: AC over Granular Base	218
GPS-2: AC over Bound Base	111
GPS-3: Jointed Plain Concrete (JPCP)	124
GPS-4: Jointed Reinforced Concrete (JRCP)	55
GPS-5: Continuously Reinforced Concrete (CRCP)	78
Total	586

The general factors considered in the GPS Section selection process were:

1. Pavement material properties
2. Pavement layer thickness
3. Traffic
4. Subgrade (fine/coarse)
5. Environment (moisture:wet/dry; temperature: freeze/no-freeze)
6. Other factors for PCC (dowels, subbase type, joint spacing, % reinforcement)

There have been, and still are, concerns about the GPS selection factors. Some of the concerns are:

<u>Material Definitions</u>

The "granular base" classification includes gravel, uncrushed gravel, crushed stone, and slag. These materials, all of which have been successfully used in flexible pavement construction, nevertheless represent a very broad range of "quality levels." Although section specific gradation data are not yet available, it is anticipated that only a limited granular base gradation range (primarily dense graded) will be encountered.

The "bound" bases include asphalt-treated materials and also "cementitiously" stabilized materials of all types. The ranges of bound base material properties (modulus, compressive strength, flexural strength, etc) covered in GPS-2 are very large.

<u>Construction Specifications and Construction Practices</u>

Factors relating to construction specifications and procedures were not included in the section selection process. The importance of specifications (such as compaction requirements) and construction practices (for example PCC jointing details) on pavement performance are well documented. It has apparently been assumed that these effects will "shake out" in the data analyses. Seasonal construction effects also were not included as a selection factor. Such items as strength gain of PCC and cementitiously stabilize base materials, PCC shrinkage cracking, the impacts of PCC "curl" stresses, etc, are very significant determinants of pavement performance.

LTPP DATA BASE MODULES

Large quantities of data are being generated in the LTPP program. The following data base modules have been developed:

1. Environmental *
2. Inventory *
3. Laboratory materials testing *
4. Maintenance
5. Monitoring
    a. Deflection *
    b. Surface distress *
    c. Profile *
    d. Rut depth *
    e. Skid resistance
6. Traffic *
7. Rehabilitation

(* Of major interest in this paper)

An overview and description of the LTPP data base and general information about accessing the data base were provided by J. Maddock of TRB during the Denver SHRP Meeting. It appears that it will be convenient to access the data base and substantial on-line capabilities will be available for "sorting through" the data base.

LTPP MATERIALS TESTING PROGRAM

A summary of the tests included in the LTPP Materials Testing Program is presented in Attachment 1. The program is considerably abbreviated from earlier versions. The reduction in the scope of the materials testing program was prompted by financial constraints. SHRP LTPP officials have suggested that some section samples (cores and/or bulk samples) may be available for future (but yet unfunded) testing. There is always the possibility of obtaining additional cores and/or bulk samples from various pavement sections of interest to a particular research effort.

IMPACTS ON PAVEMENT DESIGN

It is essential to utilize the best available "state-of-the- art" technology for analyzing the LTPP data base. There are many SHRP and NCHRP Projects (and other research efforts) that may significantly contribute to this effort. An appreciation of the "realities and practicalities" of PAVEMENTS AND MATERIALS ENGINEERING is essential.

The major pavement design procedures of current interest are the 1986 AASHTO Guide and Mechanistic-Empirical. It was indicated earlier in this paper that in the development of the 1986 Guide, the decision was made to retain the original "performance prediction" concept. However, as a result of activities associated with the development of the 1986 Guide, AASHTO decided that research should be initiated immediately with the objective of developing mechanistic pavement analysis and design procedures suitable for use in future versions of the AASHTO Guide. Project 1-26 ("Calibrated Mechanistic Structural Analysis Procedures for Pavements") is the first such NCHRP Project to be sponsored. Phase 1 of NCHRP 1-26 has been completed (2,3) and Phase 2 is in progress.

AASHTO GUIDE

The LTPP objectives include refining and improving the AASHTO pavement performance prediction equations. Detailed presentations at the Denver SHRP Meeting by Irick, Hadley, and the SHRP P-020 Contractor described various efforts that have been planned to achieve these LTPP objectives.

The LTPP data base should be helpful in evaluating the validity and veracity of changes and modifications promulgated in the 86 Guide. For example:

A. Resilient modulus for "Soil Support"

B. Layer coefficient - resilient modulus relations

C. Drainage factors

D. Environment

E. Tied shouders/widened lanes

F. Subbase erosion

G. Load equivalencies

H. Traffic

In fact, Items D, G, and H were addressed in a preliminary fashion at the Denver SHRP Meeting.

A more basic and critical issue that should be addressed in the early phase of the LTPP data analysis is:

> **Are the AASHTO PAVEMENT DESIGN / PERFORMANCE** concepts (as **presented in the 1986 AASHTO Guide) applicable, realistic, and "consistent" when objectively evaluated against a "nation-wide" data base?**

Previous studies (4,5) have indicated some of the inadequacies and limitations in the AASHTO pavement design/performance concepts. Examples are cited below.

Gomez and Thompson (4) summarized many studies which indicated the inadequacies and limitations of the "layer coeficient" concept. The LTPP data base should be helpful in considering the "validity" of the "layer coefficient" - resilient modulus relations proposed in 1986 Guide and the usefulness of the SHRP testing protocols for establishing the material "resilient modulus." If there is considerable scatter in modulus testing results (as anticipated) for a given material, the calculated "layer coefficients" will also display large fluctuations.

A major national field and analytical research project (5) for considering jointed concrete pavement performance in the USA has been conducted for the FHWA. A total of 99 jointed concrete pavement sections from four major climatic regions were included in the study. The 1986 AASHTO Guide rigid pavement design procedure was evaluated. The evaluation indicated:

> "that the AASHTO model does not adequately predict the ESALs actually sustained by the pavement sections included in the study."

The maximum number of 18 kip ESALs appied at the AASHO Road Test was 1.1 million. The design ESALs for many high volume pavement sections far exceed that value. When the predicted design ESALs are increased by the AASHTO Guide "Traffic Multiplier" to account for design reliability, the ESALs are increased even further beyond the actual AASHO Road Test traffic range. Thus, the original AASHO equations have been extrapolated <u>far beyond</u> the original data base. Perhaps, as suggested by Paul Teng of FHWA at the Denver SHRP Meeting, the 86 AASHTO Guide may be pushing the AASHTO procedures to their "extremes."

Even though, the original AASHO Road Test Report (1) indicated "structural response" as measured by surface deflection also adequately explained the AASHO flexible pavement performance (as shown in Figure 1), the choice was made to utilize the "Structural Number Concept," rather than a "pavement response" (such as surface deflection) in establishing the original AASHO Guide. The NCHRP 1-26 Project Phase 1 report (2) indicates:

> "Flexible Pavement surface deflection is a reliable structural response indicator for general performance."

It is important to note that the authenticity of the "pavement response" concept (in this case surface deflection) has persevered, while considerable concern has developed about the SN concept.

The concept of "roadbed soil resilient modulus" was included in the 1986 AASHTO Guide. The resilient modulus (M_R)is the direct input for flexible pavement design, but "k" (the modulus of subgrade reaction) is the rigid pavement design input. A proposed relation between "k" and "subgrade M_R" is presented:

$$k = M_R / 19.4$$

Where: k - Modulus of subgrade reaction, psi/inch

M_R - Resilient modulus, psi

It has been demonstrated that there is not a "unique" theoretical relation between "M_R" and "k." The comprehensive LTPP FWD deflection data base for PCC pavements can be utilized to check the validity of the "k - M_R" relation.

The 1986 AASHTO Guide also provides a procedure for considering "Loss of Support" resulting from subbase erosion and/or vertical soil movements. The suggested range for "Loss of Support Values" is from 0.0 to 3.0. The effective modulus of subgrade reaction is reduced if the "Loss of Support Value" is greater than 0. The "corrected" effective modulus of subgrade reaction may be unrealistically low (perhaps only 10 psi/inch). Many concerns have been expressed about the correction procedure. The LTPP data base should be helpful in evaluating the validity of the "Loss of Support" correction factor for rigid pavement design.

MECHANISTIC-EMPIRICAL (M-E)

The concepts of M-E design (as presented in NCHRP 1-26) are shown in the Figure 2 flow chart. Note the major elements are INPUTS, STRUCTURAL MODELS, and TRANSFER FUNCTIONS. The LTPP Program should provide valuable data and information concerning all of the elements.

Inputs

Materials Characterization - Typical issues/activities may include:

1. Evaluate the adequacy of the SHRP material testing protocols (repeatability, accuracy, etc);

2. Establish typical/generic material properties for various paving materials;

3) Evaluate/refine predictive equations for estimating material properties (modulus, etc); and

4) Establish the efficacy of "Modulus Backcalculation Procedures" for analyzing FWD deflection data.

Traffic - The traffic monitoring procedures and data reduction techniques developed for SHRP should be useful in developing improved procedures for characterizing the TRAFFIC input for M-E design. The approaches to be utilized in "traffic backcasting" for existing SHRP sections will be useful in the "calibration" activities that are associated with the development of M-E design procedures. In the "calibration" process, existing pavements are normally utilized. Thus, "traffic backcasting" is required.

Climate - The GPS pavements are located in all of the FHWA climatic regions, see Figure 3. In most cases, the initial FWD testing, coring operations, and bulk sampling are conducted concurrently, but at various times throughout the year. Thus, only one season is represented. A more comprehensive LTPP "environmental study" is under development. Witczak's Denver SHRP meeting presentation described the general thrusts of the study. The seasonal data to be collected will be very helpful in linking seasonal pavement responses and pavement performance to environmentally related (primarily temperature and moisture) material and subgrade soil property changes.

Structural Models

The FWD surface deflection data are the only structural response data available for the SHRP GPS sections. The availability of related paving material and subgrade soil information (there is an FWD deflection basin for the test-pit location) provides an excellent opportunity for evaluating and verifying structural models. Some of the model factors that may be evaluated are 1) load level effects 2) pavement material effects 3) pavement cross section effects 4) seasonal effects and, 5) load transfer at joints and load placement effects in PCC pavements.

Transfer Functions

The basic premise of M-E design is that:

Pavement distress development can be related to pavement structural responses (stress, strain, deflection).

The dominant flexible pavement distresses normally considered in M-E design are fatigue cracking and rutting. The dominant rigid pavement distresses are cracking, faulting, pumping/erosion, and CRCP "punchouts."

The LTPP data may be helpful in:

1) Better understanding the evolution and "patterns" of flexible and rigid pavement distress development;

2) Improving/refining/developing current and/or new "distress algorithms"; and

3) Further considering and identifying the dominant "Cause - Effect" relations for the initiation and development of various flexible and rigid pavement distresses.

Many distress development algorithms are of a "Distress-Log N" form. Thus significant additional distress <u>may not</u> accumulate within the short time monitoring increments used in LTPP, or within the "first five years." The value of longer term monitoring data is obvious.

M-E design concepts and approaches can more readily accomodate new materials, changed loading conditions, and "innovative" cross-sections than an empirically based procedure, such as the 1986 AASHTO Guide. It is recommended that M-E concepts also be utilized in analyzing the LTPP data base. If the "pavement performance prediction" based design philosophy that has been included in all versions of the AASHO (AASHTO) Guide is not validated in the early phases of the LTPP data base analysis and evluation activities, the M-E approach <u>should receive additional future emphases</u>.

LTPP DATA BASE CONCERNS

There are concerns about various components of the LTPPP data base. The materials, traffic, and monitoring data modules are of particular interest.

MATERIALS

The LTPP materials testing program is summarized in ATTACHMENT 1. Some of the concerns are:

1. The material samples are not from the test section proper.
2. There is <u>NO</u> strength testing of any type for either the granular materials or the subgrade soils.
3. There are <u>NO</u> tests on "recovered asphalt cement."
4. Is it correct to assume that "current material and soil

properties" are representative of "as constructed" and "early life" conditions?

TRAFFIC

Hollenbeck's presentation at the Denver SHRP Conference indicated the nature of the considerable difficulties encountered in monitoring current and future SHRP section traffic and in the development of procedures for "backcasting traffic." In addition to these considerations, other traffic related factors include tire pressures, "early life" loading (excessive fatigue consumption may be effected), and "overloading" history (one heavy load may be sufficient to crack a cementitious paving material layer).

MONITORING DATA

The <u>initial</u> monitoring data for the existing LTPP GPS sections will indicate pavement "distresses" of varying magnitude and severity. Subsequent monitoring data will be periodically collected. Relevant issues/questions concerning the analysis of the initially noted distress data include:

1. When did the noted initial distress initiate in the life of the pavement?

2. Will there be adequate documentation for following the "rapid development" of pavement distress?

3. Is the traffic data base adequate for explaining flexible pavement rutting which is "stress-history" dependent for certain paving materials and subgrade soils?

PAVEMENT DESIGN - PAVEMENT PERFORMANCE PREDICTION

The NCHRP 1-26 Project Phase 1 report (2) emphasizes that pavement design is:

AN "A PRIORI" PROCESS

The inputs identified in Figure 2 are generally not well defined and or quantified at the time of the original design. The quality and characteristics of the "as-built" pavement are obviously not known.

Procedures for predicting future "pavement performance" are utilized in pavement management systems. When pavement construction is completed, a "finished product" is available. Detailed and refined inputs (layer thicknesses, material properties, construction records, FWD data, early life performance, etc) are available for subsequent use in predicting pavement performance. Pavement performance models can be "project specific" since they can be calibrated based on the "early life performance" information for a particular project. By the time a "more precise" pavement condition prediction is needed for establishing future maintenance and/or rehabilitation activities, the "calibrated project specific" performance model will be available.

It is recommended that the pavements and materials community recognize the distinction between "A PRIORI PAVEMENT DESIGN" and "PAVEMENT PERFORMANCE PREDICTION" activities. The activities are complementary, but a PAVEMENT DESIGN procedure is not necessarily the inverse of a PAVEMENT PERFORMANCE PREDICTION MODEL.

SUMMARY

When completed, the LTPP data base will represent a comprehensive pavement data base established from consistent and rigorously controlled evaluation and testing procedures. The LTPP GPS flexible and rigid pavement sections include a wide range of paving materials, cross-sections, subgrade soils, traffic levels, and environment. Although there are concerns about some aspects of the LTPP data base, it will be valuable and widely utilized in future pavement analysis/design and pavement performance studies. It will be possible to supplement some portions of the data base by additional future testing and evaluation. Some have suggested that "forensic" investigations of failing and/or failed GPS sections would be helpful. The fact that pavement monitoring will be extended beyond the initial 5 year period and the inclusion of SPS section data will further strengthen the LTPP data base and increase its usefulness. The TRB data base management system will provide easy and convenient access to the LTPP data, thus facilitating extensive and comprehensive studies.

A very important and significant early use of the LTPP data base is to consider the following issue:

> **Are the AASHTO PAVEMENT DESIGN / PERFORMANCE concepts (as presented in the 1986 Guide) applicable, realistic, and "consistent" when objectively evaluated against a "nation-wide" data base?**

The consideration should include all of the important aspects of the 1986 AASHTO Guide design process (traffic, paving material characterization, subgrade soil evaluation, environmental effects, etc).

The results of this consideration will obviously heavily impact subsequent LTPP data base analyses which at present are primarily oriented toward modifying, refining, improving, etc the 1986 AASHTO Guide.

The LTPP data base also presents many opportunities for considering the Mechanistic-Empirical (M-E) pavement analysis and design design concepts and principles shown in Figure 2.

<u>REFERENCES</u>

1. "The AASHO Road Test - Report 7 - Summary Report," Special Report 61G, Transportation Research Board, 1962.

2. "Volume I - Final Report," NCHRP 1-26, Calibrated Mechanistic Structural Analysis Procedures for Pavements, University of Illinois at Urbana-Champaign, Construction Technology Laboratories (A Divisuion of The Portland Cement Association), and The Asphalt Institute, March, 1990.

3. "Volume II - APPENDICES," Final Report, NCHRP 1-26, Calibrated Mechanistic Structural Analysis Procedures for Pavements, University of Illinois at Urbana-Champaign, Construction Technology Laboratories (A Division of the Portland Cement Association), and The Asphalt Institute, March, 1990.

4. Gomez, M., and M. R. Thompson, "Structural Coefficients and Thickness Equivalency Ratios," Civil Engineering Studies, Transportation Engineering Series No. 38, University of Illinois at Urbana-Champaign, 1983.

5. Smith, K. D., et al, "Performance of Jointed Concrete Pavements," Volume III - Summary of Research Findings, FHWA-RD-89-138, Federal Highway Administration, July, 1990.

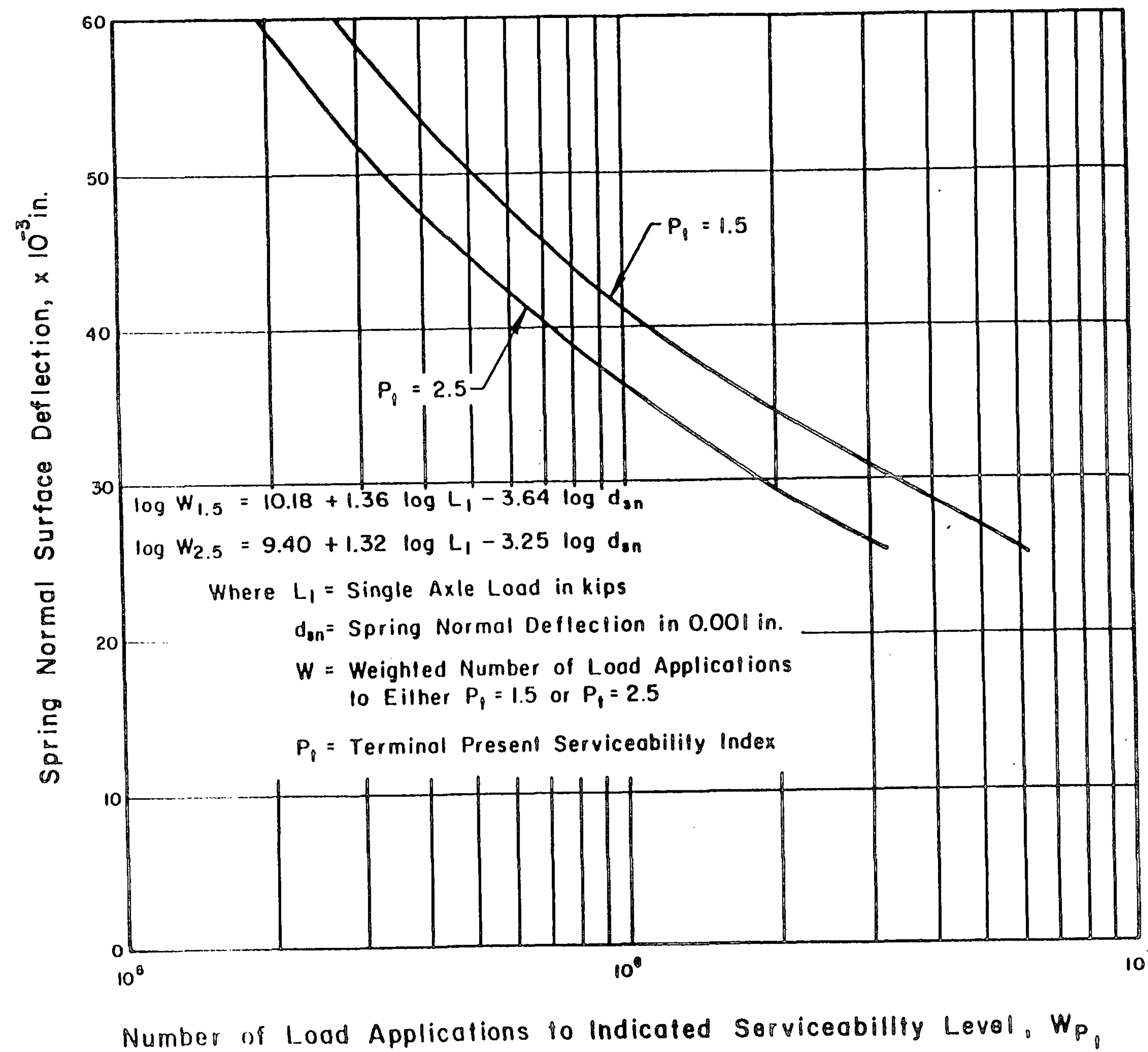


Figure 1. AASHO Road Test Deflection-Life-Serviceability Relations.

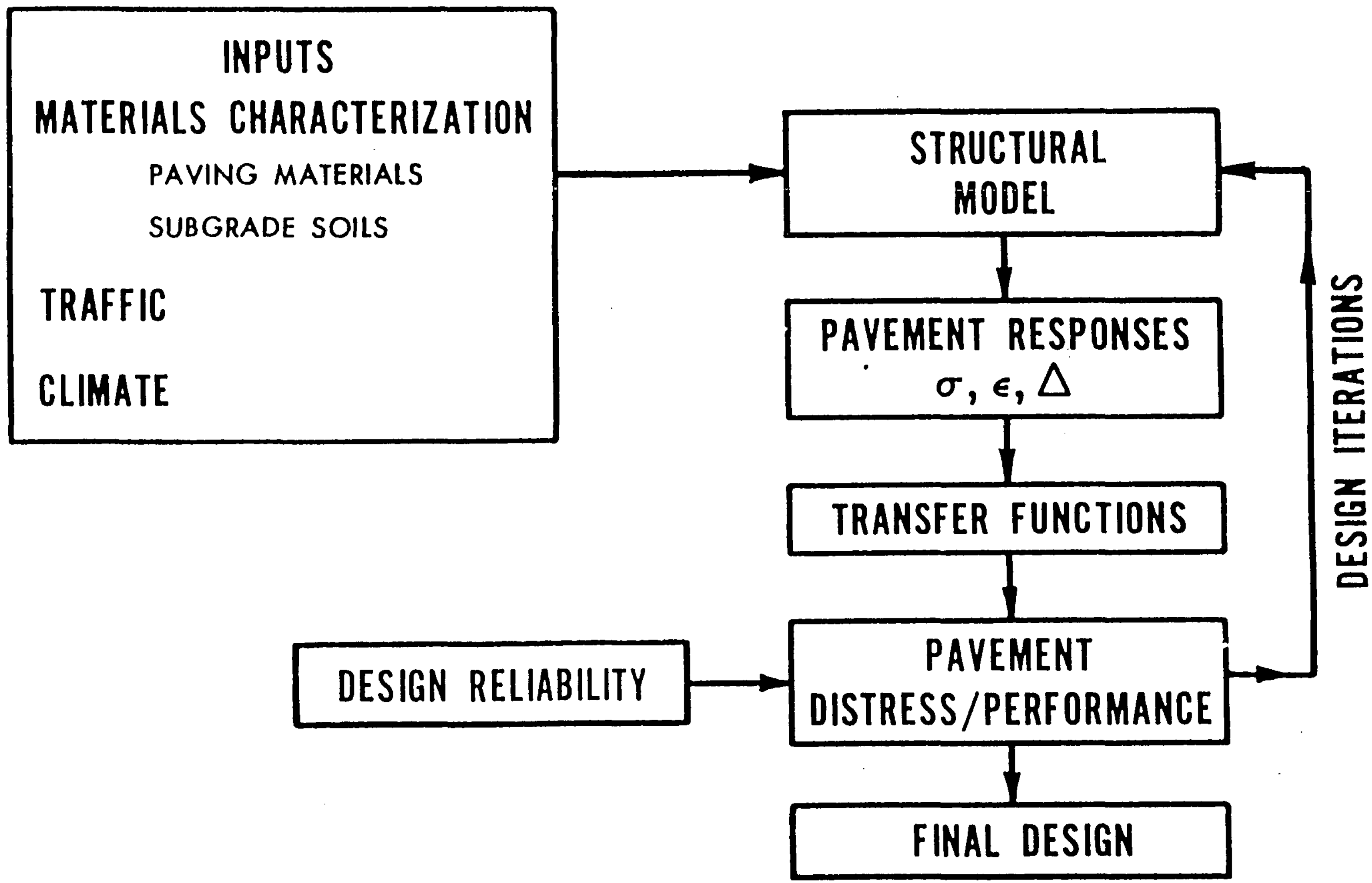
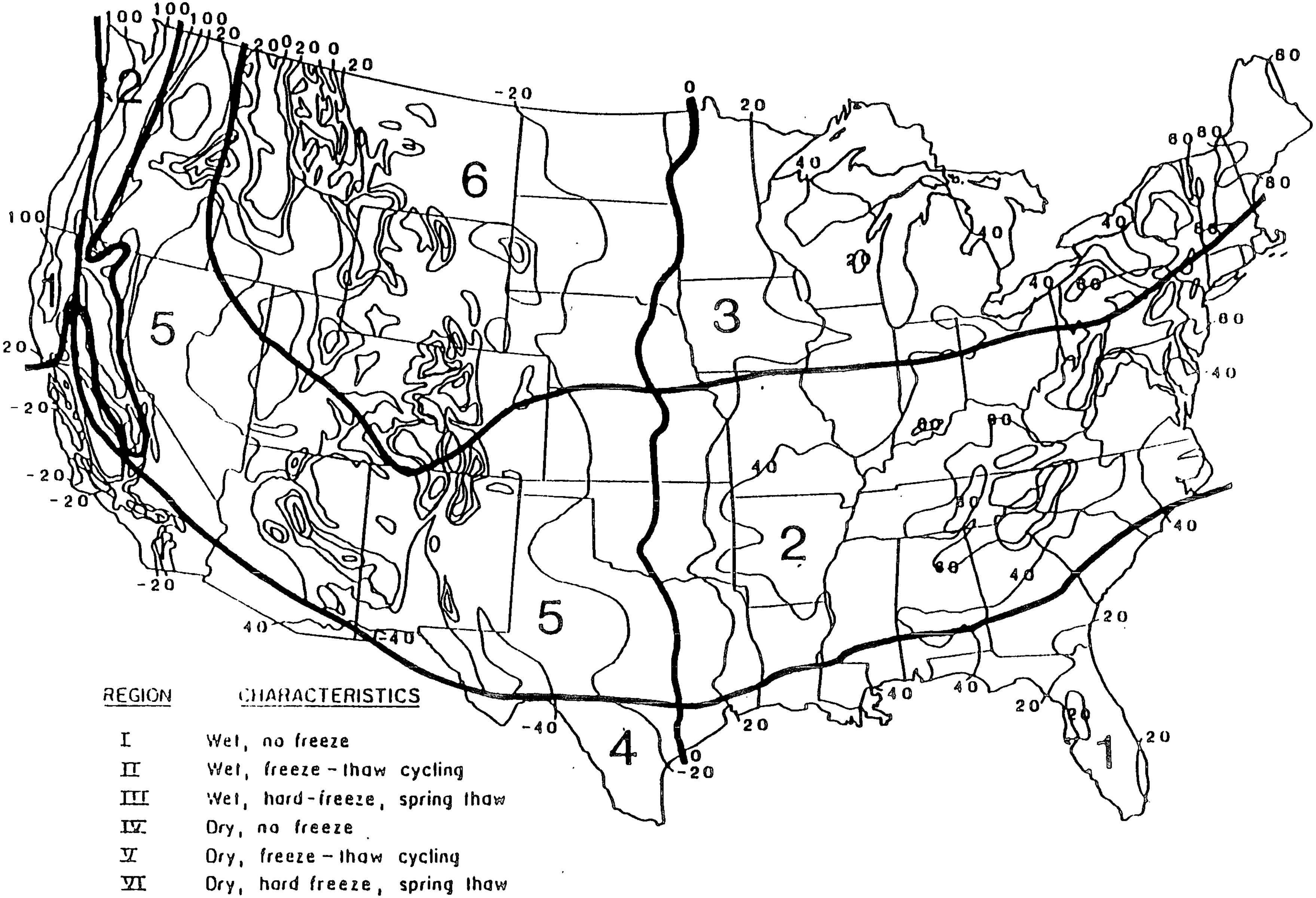


Figure 2. Components of a Mechanistic-Empirical Design Procedure.



Identified in the AASHTO Design Guide

ATTACHMENT 1

FIELD AND LABORATORY MATERIAL TESTS FOR GPS EXPERIMENTS

FIELD

Nuclear density/moisture (untreated base, subbase, subgrade)

LABORATORY	SHRP Protocol
Asphalt Concrete	
Core examination and layer thickness	P-01
Bulk specific gravity	P-02
Maximum specific gravity	P-03
Asphalt content (extraction)	P-04
Resilient modulus (includes tensile strength)	P-07
Extracted Aggregate (Per layer)	
Gradation	P-14
Particle shape - fine aggregate (NAA)	P-14A
Treated Base and Subbase (Per layer)	
Identification and description	P-31
Compressive strength (other than asphalt treated material)	P-32
Resilient modulus (asphalt treated material)	P-33

<u>Unbound Base and Subbase</u> (Per layer)

Atterberg limits	P-43
Moisture-density relationship	P-44
Resilient modulus	P-46

<u>Subgrade</u>

Classification and description	P-52
Moisture content	P-49
Sieve analysis (included washing)	P-51
Hydrometer analysis	P-42
Atterberg limits	P-43
Moisture-density relationship	P-55
Resilient Modulus	P-46

<u>Portland Cement Concrete</u>

Core examination and layer thickness	P-66
Compressive strength	P-61
Splitting tensile strength	P-62
Static modulus of elasticity	P-64

Pavement Rehabilitation: Selection And Design

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1.0 LTPP Maintenance And Rehabilitation Objectives

The overall LTPP goal mentions both rehabilitation and maintenance:

> "**To increase pavement life** by investigation of various designs of pavement structures and **rehabilitated pavement structures**, using different materials and under different loads, environments, subgrade soil, and **maintenance practices.**"

The main LTPP objective concerning rehabilitation is to "**develop improved design methodologies and strategies for the rehabilitation of existing pavements.**" A strategy includes both the selection of rehabilitation treatments, and the timing of the actions.

An objective concerning maintenance is to "**determine the effects of . . . maintenance levels on pavement distress and performance.**"

This presentation summarizes the LTPP maintenance and rehabilitation (M&R) experiments, presents a summary of what is needed overall in M & R technology, and finally what is expected to be obtained from the LTPP M & R experiments. Note that both "maintenance" and "rehabilitation" activities are included in this presentation. Keeping a pavement in-service involves both activities.

2.0 LTPP Rehabilitation and Maintenance Experiments

There are at least nine different in-service pavement experiments that will contribute performance data and information to maintenance and rehabilitation. These include the following:

GPS 6 AC Overlay Over AC Pavement
GPS 7 AC Overlay Over JCP Pavement
GPS 9 Unbonded PCC Overlay Over PCC Pavement

SPS 3 Preventive Maintenance Effectiveness of Flexible Pavements
SPS 4 Preventive Maintenance Effectiveness of Rigid Pavements
SPS 5 Rehabilitation Of Asphalt Concrete Pavements

SPS 6 Rehabilitation Of Jointed PCC Pavements
SPS 7 Bonded Concrete Overlays Of Concrete Pavements
H106 Improved Maintenance Materials and Procedures

A summary of the main experimental factors and their levels for each of these experiments are shown in Figures 1 to 11. Several of these experiments have a very limited number of cells that are filled with test sections, and therefore not all of these factors can be evaluated independently.

In addition to the main experimental factors, there exists many different co-variables. These are variables that are collected from individual test sections but are not varied in a planned way throughout the experiment. Many of these variables will have a significant range throughout the experiment and may very well show some significance. Examples of co-variables include:

Subgrade properties (PI, resilient modulus, degree of saturation)
Material properties (gradation, strength, durability)
Deflection parameters (maximum deflection, basin area)
Calculated mechanistic parameters (strain, stress, fatigue damage)
Climatic factors (freezing index, annual minimum temperature)
Etc.

Figure 1. GPS 6
AC Overlay Of AC Pavement
6A Existing Overlays

Climate:	Wet Freeze, Wet Non-freeze, Dry Freeze, Dry Non-freeze
Subgrade:	Fine, Coarse
Traffic:	Low, High
Exist Structure:	Low, High
OL Thick:	Low, High
OL Stiffness:	Low, High

Figure 2. GPS 6
AC Overlay Of AC Pavement
6B To Be Constructed

Climate:	WF, WNF, DF, DNF
Subgrade:	Fine, Coarse
Traffic:	Low, High
Exist Structure:	Low, High
OL Thick:	Low, High
Exist Condition:	**Poor, Good**

Figure 3. GPS 7
AC Overlay Of PCC Pavement
7A Existing Pavements

Climate:	WF, WNF, DF, DNF
Subgrade:	Fine, Coarse
Traffic:	Low, High
Pavement Type:	Jointed Plain, Jointed Reinforced, Continuously Reinforced
OL Thick:	Low, High
OL Stiffness:	Low, High

Figure 4. GPS 7
AC Overlay Of PCC Pavement
7B To Be Constructed

Climate:	WF, WNF, DF, DNF
Subgrade:	Fine, Coarse
Traffic:	Low, High
Pavement Type:	JP, JR, CR
OL Thick:	Low, High
Exist Cond:	Poor, Good

Figure 5. GPS 9

Unbonded PCC Overlay
On PCC Pavement

Climate:	WF, WNF, DF, DNF
Pavement Type:	JP, JR, CR
OL Thick:	Low, High
OL Type:	JP, JR, CR

Figure 6. SPS 3
Preventive Maintenance
Effectiveness Of Flexible Pavements

Climate:	Freeze, No Freeze
Subgrade:	Fine, Coarse
Traffic:	Low, High
Structure:	Low, High
Pavement Cond:	Good, Fair, Poor
Maint. Treat:	Do Nothing Crack Seal Chip Seal Slurry Seal Thin AC OL

Figure 7. SPS 4
Preventive Maintenance
Effectiveness Of Rigid Pavements

Climate:	Freeze, No Freeze
Subgrade:	Fine, Coarse
Traffic:	Low, High
Subbase:	Granular, Stabilized
Pavement Condition:	Good, Fair, Poor
Maint. Treatment:	Do Nothing Crack Seal Joint Seal Underseal

Figure 8. SPS 5
Rehabilitation Of
Asphalt Concrete Pavements

Climate:	WF, WNF, DF, DNF
Exist Condition:	Fair, Poor
Pre-OL Repair:	Minimum, Intensive
Rehabilitation:	Do Nothing (GPS) OL thick: 2, 5 in AC OL Type OL: virgin, recycle

Figure 9. SPS 6
Rehabilitation Of
Jointed PCC Pavements

Climate:	WF, WNF, DF, DNF
Exist Cond:	Fair, Poor
Pre-OL Repair:	Minimum, Maximum
Rehabilitation:	Do Nothing (GPS) Restoration (CPR) Crack/Seat AC OL (4, 8 in) Conv. AC OL w/ Saw Seal Conv. AC OL

Figure 10. SPS 7
Bonded Concrete Overlays Of Concrete Pavements

Climate:	WF, WNF, DF, DNF
Pvt. Type:	JCP, CRCP
Surface Prep:	Coldmill, Sandblast, Shot Blast
Bond Agent:	None, Cement Grout
PCC OL Thick:	3, 5 in

Figure 11. H106
New/Improved Maintenance Materials And Procedures

AC crack sealing

PCC joint sealing

AC pothole repair

PCC spall repair

3.0 What Is Needed to Improve Maintenance And Rehabilitation Selection And Design?

Figure 12 shows the overall flow of procedures needed in the selection and design of maintenance and rehabilitation (M & R) for a given pavement section. Key data and information is needed from the pavement section for use in formulating maintenance and rehabilitation treatments and designs. Predictive procedures, or models/equations, are then needed to project future performance if a certain M & R treatment and design is specified. The life of the M & R treatment can then be determined. A knowledge of treatment life and costs lead to the estimation of life-cycle costs associated with the pavement facility. There are other costs, including user costs, that should also be considered.

Figure 13 shows an illustration of the type of predictive capability needed for determining the effect of timing (or existing pavement condition) on the future performance or consequence of many M & R treatments.

Figure 14 shows an illustration of differing M & R treatments applied at the same time to a pavement. The consequences of these actions are illustrated.

The heart and soul of improved maintenance and rehabilitation are predictive models or equations that show the **consequence** of any M&R treatment applied under any pavement condition. For example, "If maintenance treatment X or rehabilitation treatment Y were applied to this pavement, what would be the consequence (future distress, roughness)?" This capability permits the prediction of treatment life, and thus, life-cycle cost and relative cost-effectiveness.

Will LTPP produce the needed models/equations to determine the consequences of M & R treatments? Adequate prediction models require the following:

Database:	Must cover scope of M & R treatments and existing pavement conditions
Y Variables:	Visual Distress Roughness Friction

X Variables:	Pavement design
	Pavement materials/soils
	Pavement condition (interaction of distresses)
	Mechanistic variables and "clusters" of variables
	Traffic / climate
	Previous maintenance
	M & R treatment
	    design
	    materials
	    construction

4.0 What Can And Cannot Be Obtained From LTPP To Improve Maintenance And Rehabilitation Selection And Design?

Effects of the following variables CAN most likely be obtained from LTPP to improve M & R selection and design, assuming that the experimental cells are filled with test sections.

Pre OL:	Exist pavement structural adequacy	
	Repair extent:	Do nothing Crack seal Minimum to maximum repair prior to overlay
Do Nothing:	For comparison purposes	
Seal Coats:	Chip seal, slurry seal	
OL Design:	Type OL:	AC conventional AC break/crack and seat PCC AC saw and seal over joints PC unbonded PC bonded
	Thickness AC Stiffness AC recycled overlay	
Traffic:	Low, High	
Climate:	Most zones	
Subgrade:	Fine, Coarse	
Maintenance Materials:	Crack seals Joint seals AC potholes PC spalls	

The following most likely cannot be obtained from LTPP to improve M & R selection and design.

Limitations of database

- Many missing sections will cause gaps in results
- Missing factors (some material and other factors that may be significant are not being measured)

Comprehensive prediction models

1992 results will be limited due to lack of data.

Other types of M & R not included

Various seal coats
Rejuvinators
Widening to Lanes
Adding lanes
Shoulder M & R
Effect of edge drains
AC recycling variations
PCC recycling

Second rehabilitations? (GPS?)

Many existing rehabilitated pavements need another rehabilitation. This is not included in LTPP.

Reflection crack control

Many options not being tested.

New materials performance

Many new material possibilities not being tested.

M & R for low volume roads

Such as existing gravel and seal coat surfaces.

5.0 Conclusions

- LTPP experimental sections provide far more actual data on M & R than has ever before existed. There will be many uses made of the data to improve rehabilitation and maintenance construction specifications and standards, design and pavement management needs (such as information for life-cycle costing). The development of performance models that predict the consequences of a M & R treatment will be most valuable.

- Many of the experiments do not yet have adequate cells filled, such as GPS 6A and 6B, 7A and 7B and 9. With renewed efforts adequate sections can be obtained. Some construction of sections to fit these cells may be necessary. The use of GPS 1 - 5 sites for GPS 6, 7 and 9 sites when they are rehabilitated would be helpful.

- States that supplement existing M & R sections with additional sections specifically related to their needs and interests will greatly improve the usefulness of the data for themselves and other states.

- The use of GPS 6 and 7 test sites for second rehabilitation testing is extremely important, because a there exists a large number of pavements that have already been rehabilitated at least once and there exists very limited knowledge on how to design the additional rehabilitations.

- There will be some useful prediction models for several key M & R treatments in a few years, but the most data will not be available for at least five years, a particularly after some time sequence data has been obtained.

FIGURE 12

Maintenance and Rehabilitation Selection and Design

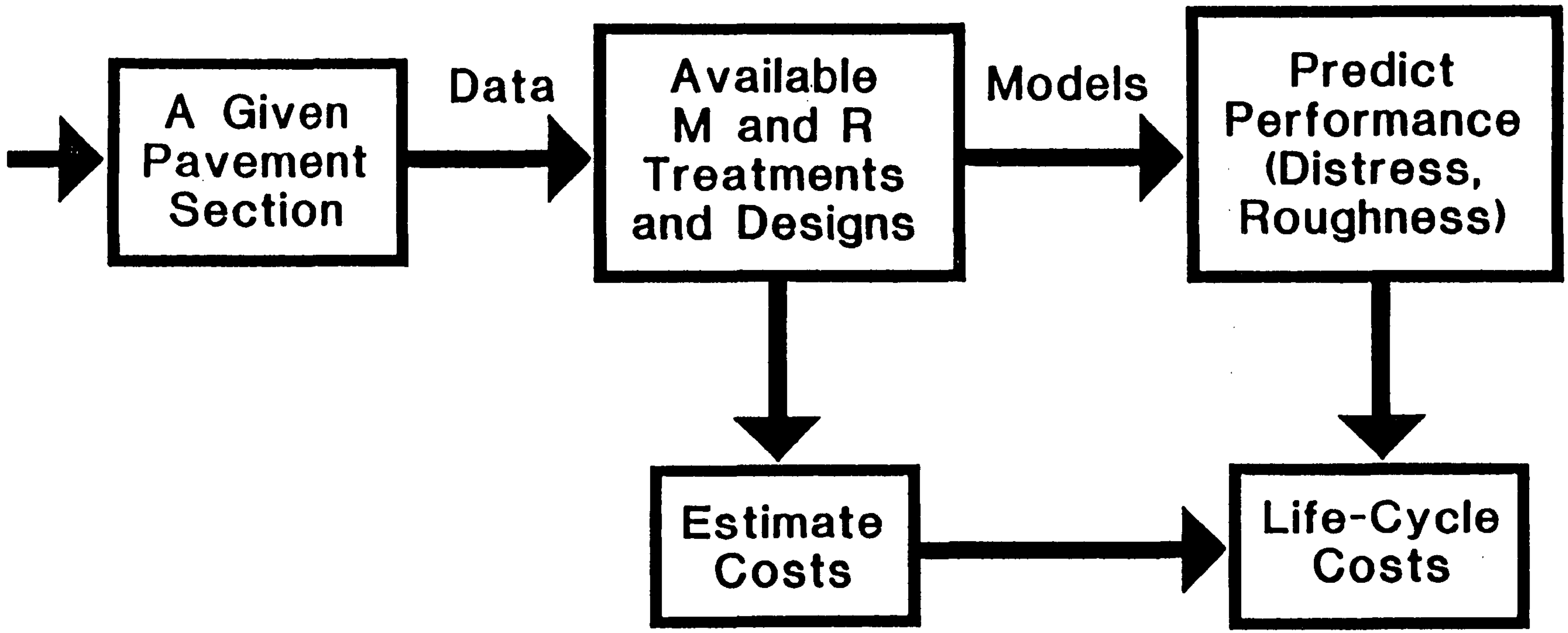


FIGURE 13

Consequence of Timing for Maintenance and Rehab

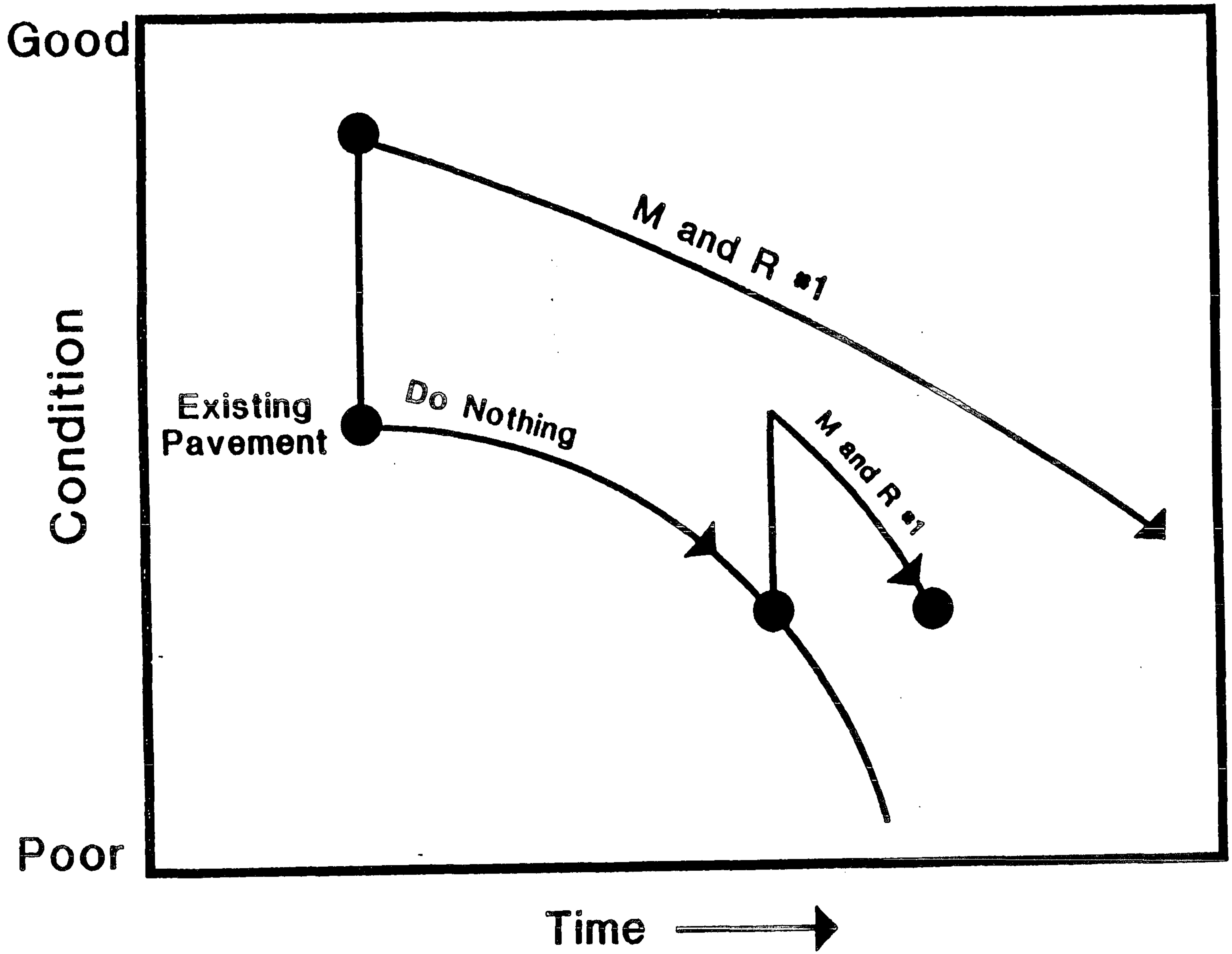
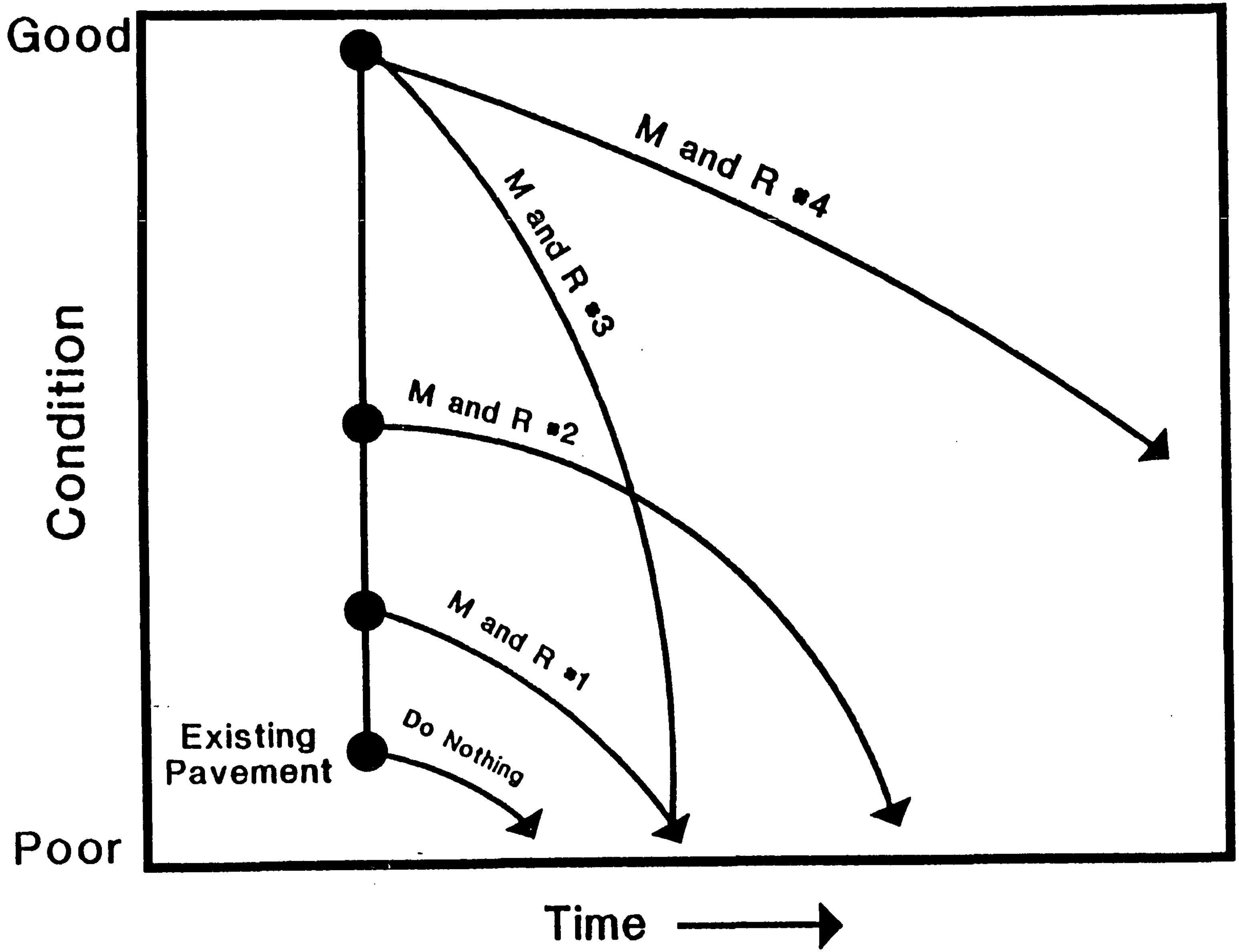


FIGURE 14

Consequence of Different Maintenance and Rehab Treatments



PAVEMENT TYPE SELECTION AND LIFE-CYCLE COSTS

IMPLICATIONS FOR LONG-TERM PAVEMENT PERFORMANCE (LTPP)

by

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INTRODUCTION

Setting the Stage

In this paper we consider Long-Term Pavement Performance (LTPP) within the context of pavement life-cycle costs. Type selection will provide a convenient example of the kinds of benefits that could be derived from LTPP and the considerations that need to be given in planning and executing the field data collection and subsequent analyses. However, the potential of LTPP to serve the needs of life-cycle analyses is such a rich field that many other examples could have been provided. Indeed, other potential applications of LTPP data to life-cycle costs will be cited in some of the examples below.

The implied breadth of this topic therefore suggests a format and approach somewhat different from that taken in many other papers on LTPP in this conference:

- The need to take a broad, programmatic view of LTPP, rather than focusing on its specific aspects or details.
- An emphasis not on how the LTPP experiments are designed, but rather on how the expected results may be used.
- A need to consider future developments in LTPP beyond the 1993 nominal completion of the SHRP program.
- An understanding of how the several LTPP projects relate not only to one another, but also to SHRP projects in other program areas outside LTPP.

To establish a point of view for this paper, we will adopt the perspective of an enlightened, 21st-century pavement manager: someone knowledgeable of the engineering, economic, and management issues related to pavements. This manager desires to understand better how LTPP data may be applied to improve predictions of life-cycle costs, so that better long-term pavement decisions can be made.

Concepts and Applications of Life-Cycle Costs

Life-cycle costing involves predicting the streams of total costs and benefits that result from decisions made now or in the future. Decisions involve choices among options or alternatives. With pavements, these decisions may affect, for example, the types of repair actions to be taken, when they are to be taken, where they are to be taken, and how they are to be accomplished throughout a road network. The objective of the entire exercise is to determine what set of actions (or decisions) will yield either the maximum total discounted benefits or the minimum total discounted costs (if benefits are not explicitly considered or are reduced to equivalent reductions in costs). Since life-cycle analyses are conducted through the period of expected pavement service life (or at least some major interval thereof), it provides the analytic capability to reach a solution that is efficient over the long term.

The concept of life-cycle costs is not new. Within the U.S. the relevance of this concept to highway transportation has been recognized for over one hundred years. With the advent of computers in the 1960s, the practical application of this economic approach to highway design and maintenance standards of regional or national road networks was pursued by international lending agencies such as the World Bank, other international lending institutions, and the U.S. Agency for International Development. The results of these efforts helped spur the inclusion of economic analyses in U.S. practice (e.g., the incorporation of user costs and benefits as well as agency costs in pavement management and other highway management systems). A more focused concentration on life-cycle costing has been prompted recently, however, by two federal policy initiatives that will guide future transportation policy and, by implication, will also influence future directions of pavement management: (1) the U.S. Department of Transportation's National Transport Policy[1], and (2) the Federal Highway Administration's (FHWA's) new policy on pavement management and eligibility of pavement projects for federal aid[2].

DOT's National Transport Policy is a broad, comprehensive statement of federal objectives, priorities, and strategies in highways and other modes of transportation. It proposes a more flexible, productive investment policy in a maturing transportation system, recognizing that maintaining existing transportation assets is "the most immediate task for the transportation sector." The national policy envisions this task as a shared responsibility, with the federal government emphasizing capital repairs in its aid programs, and state and local governments taking the lead in managing facilities and maintaining them. Although the DOT policy statement does not address itself to specific methods of analysis, its encouragement of a broader range of options and its goal to eliminate "unnecessary or unwise investment" is certainly consistent with the objectives of life-cycle costing.

The FHWA policy on pavements requires states to implement pavement management systems by 1993. It describes the systems requirements and their proposed applications to specific highway functional classes in the federal aid system. A life-cycle economic analysis is specifically proposed as the framework within which pavement alternatives will be evaluated; however, the details of how to implement these cost procedures are at the discretion of the states, and some flexibility is intended in how each state tailors the analytic procedures to its own situation and management needs. The FHWA policy statement suggests the provisions of the 1986 AASHTO Pavement Design Guide as a technical reference for pavement design and type selection.

SHRP LTPP Design

Two additional references provide a point of departure for considering the use of LTPP results in economic analysis of pavement alternatives. The first is the comprehensive research plan prepared by SHRP in 1986, which outlines the objectives and the proposed experimental designs for LTPP (as well as

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[1]U.S. Department of Transportation, Moving America: New Directions, New Opportunities, A Statement of National Transportation Policy Strategies for Action, Washington, D.C., February 1990.

[2]Federal Highway Administration, revisions to the Federal-Aid Highway Program Manual (vol. 6, chap. 2, section 4, subsection 1: Pavement Management and Design Policy), Transmittal 428 (HHO-12), March 6, 1989.

for other SHRP programs)[3]. The second is the 1986 edition of AASHTO's Pavement Design Guide, which describes not only technical relationships for the analysis and design of both rigid and flexible pavements, but also a proposed framework for economic analysis (including type selection)[4]. The provisions of both of these references will be cited below in reviewing the following:

- how the LTPP results may assist in the analysis of pavement life-cycle costs; and
- what areas of LTPP study design and implementation need to be emphasized or perhaps modified to promote the application of LTPP results to economic analyses and more broadly to pavement management.

SHRP's 1986 research plan proposed two series of pavement studies: the General Pavement Studies (GPS) and the Specific Pavement Studies (SPS). The experimental designs of both of these studies have been modified since their inception as the result of further engineering and statistical reviews and practical considerations involving site availability and selection. These details of the GPS and SPS experimental designs, including what modifications have been made and why, are discussed at length in several other papers being presented at this workshop, and will therefore not be repeated here. Rather, we focus below on the implications of life-cycle costs for <u>both</u> GPS and SPS, regarding them as two aspects of a single basic data gathering effort to better understand pavement behavior.

IMPLICATIONS OF LIFE-CYCLE COSTS FOR LTPP

Life cycle costs and pavement type selection have several implications for LTPP data collection and analysis, as described in the paragraphs below:

1. Life-cycle cost analyses will require comprehensive pavement performance models drawing from all LTPP studies. GPS and SPS experiments must therefore begin to be viewed as parts of a unified experimental program in their objectives, methods, analyses, and results. Procedures followed by LTPP contractors (both in field data collection and in analysis of results) must ensure that GPS results and SPS results are thoroughly integrated within one consistent set of findings, not two. Life-cycle cost analyses will require the best available predictions of pavement deterioration (and the factors that influence the rate of deterioration), as well as estimates of the beneficial effects and costs of different repair actions. The contributions of both the GPS and the SPS findings will be needed for the successful development of these analytic models. Several other points below will reinforce this idea.

2. The results on maintenance and rehabilitation to be obtained in SPS are as important as those to be obtained for pavement design in GPS. Why? Because managers increasingly will come to see their options as involving tradeoffs among a range of pavement actions, from capital-intensive projects

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[3] <u>Strategic Highway Research Program: Research Plans</u>, Transportation Research Board, Washington, D.C., May 1986.

[4] <u>AASHTO Guide for Design of Pavement Structures</u>, American Association of State Highway and Transportation Officials, Washington, D.C., 1986.

involving rehabilitation or reconstruction to more modest repairs and routine maintenance. Life-cycle cost analyses help structure these alternatives to illustrate the tradeoffs involved.

3. A corollary to items 1 and 2 is that the focus of LTPP should be on pavement performance rather than on pavement design. Good performance models can always be used for design; however, design models are not always suitable for predicting pavement performance. In some sense the distinction between GPS and SPS has created an artificial barrier between those experiments investigating the role of different pavement design parameters and other experiments testing the influences of factors such as maintenance effectiveness and rehabilitation actions on subsequent pavement behavior. When the entire problem is viewed broadly (especially with life-cycle costing in mind), it is the ability to predict pavement performance that is the objective, influenced not only by the standard of design but also by the quality of construction, variations in expected traffic and environmental loadings, time-dependent changes in pavement structural and materials properties (e.g., water infiltration, effects of aging), and subsequent maintenance and rehabilitation. (The need for performance models will be reinforced in later sections.)

4. Relatively small, potentially inexpensive changes in LTPP procedures could yield payoffs in results useful to life-cycle cost analyses. For example, guidelines governing routine maintenance of GPS sites allow states to employ their normal maintenance practices with no attempt at nationwide standardization of methods, frequency, condition thresholds, or quality of maintenance. Yet, it is these types of periodic maintenance actions that are the subjects of H-101 in the SPS. With a little more guidance on the maintenance of GPS sections, states would have potentially a second source of maintenance data available that would complement (not duplicate) the H-101 studies. From a life-cycle cost perspective this type of consideration is important, since maintenance has received such little research attention in the past.

5. The analyses of LTPP data will be just as important, if not more so, than the data collection effort itself, for the following reasons:

- A good conceptual framework for life-cycle cost analyses of pavements in the context of U.S. conditions has not yet been disseminated among highway practitioners. The discussions on the subject in Part 1 of the 1986 AASHTO Guide provide many good points, but these are of a rather practical, procedural nature. More general, fundamental issues need to be understood, particularly from an economic standpoint. While many of these issues are outside the scope of LTPP, the fact remains that there is no broadly conceived engineering or economic blueprint to guide the development of pavement performance models suitable for life-cycle cost analysis.

- There are technical hurdles that need to be overcome in developing viable performance models for life-cycle cost analyses, going beyond the usual problems of data quality and the appropriate techniques of statistical analysis. For example, performance models for life-cycle costs ideally should account for the positive contributions of maintenance and rehabilitation as well as the negative effects of deterioration in predicting future pavement condition. There is, however, relatively little experience in composing pavement models that explicitly account for the effects of maintenance and rehabilitation. (Indeed, SHRP Project H-101 has as one of its objectives the formulation of models of pavement routine maintenance, based upon results derived from selected SPS sections.) As another example, it would be desirable to account for interactions among different types of distress, rather than assuming independence among damage mechanisms as is the common practice today. (Such interactions are essential in modeling the effects of water infiltration on pavement materials properties and acceleration of certain types of distress, for instance.) In their analyses of LTPP data, SHRP contractors will have to contend with these technical issues in formulating performance models.

6. The 1993 target date for states' implementation of type selection and life-cycle costs in pavement management should be taken into account in the plans for analyzing LTPP findings. This does not mean that all LTPP work contributing to life-cycle cost approaches must be completed by 1993--that deadline would be neither possible nor desirable. Rather, the 1993 target proposed by FHWA could be viewed more as an opportunity for the SHRP LTPP program to provide leadership and national focus in the advancement of pavement management, and to sustain this effort through the '90s into the next century. To do so, however, the SHRP LTPP team would need to continually anticipate developments in both the technical and the policy areas of pavement management, and to gear or redirect LTPP findings toward those ends.

Let us assume that the LTPP program recognizes and responds to these challenges in applying life-cycle costs to pavement management. What specific advances could or should we expect from LTPP, and when? Detailed predictions and timetables are always risky and subject to change in an undertaking as large, complex, and subject to pitfalls as LTPP. Nevertheless, a realistic progression of accomplishments can be envisioned for LTPP, broadly divided into near-term and long-term possibilities.

NEAR-TERM OBJECTIVES, POSSIBILITIES, AND IMPLICATIONS

Near term objectives and accomplishments would forge a link between current practice and future possibilities. They would focus on building upon what exists today--e.g., the concepts and design procedures in the AASHTO Guide--and to modify and extend existing methods to the new approaches implied by life-cycle costs. This process of adaptation could proceed in stages, from relatively modest technical revisions to existing design formulas, to more fundamental shifts in concepts and methodologies of pavement analysis. Several possibilities are discussed in each of the sections below.

Technical Revisions to AASHTO or Other Design Formulas

LTPP results can contribute to technical revisions in the AASHTO design formulas for new pavements and pavement rehabilitation, and assist states in revising or recalibrating other design procedures that they may use. These types of advances represent the first tier of applications of LTPP results, and are probably the ones most often anticipated when considering the potential benefits of LTPP. The field verification and refinement of key pavement engineering relationships are directly or indirectly considered in several other workshop papers (particularly related to pavement design), and therefore need not be discussed in more technical detail here. Furthermore, the value of comprehensive data on pavement performance reinforces the importance of companion studies by states to provide additional data points and help to adjust LTPP findings to local conditions.

Other workshop papers on LTPP discuss the engineering parameters important to pavement design and analysis--structural and materials characteristics, traffic loads, environmental zones, etc.--and relate these to the statistical requirements of LTPP site selection. These statistical considerations are important and necessary to ensure proper coverage and validity of the LTPP experiments. It is important, however, that the analyses of these data leading to new or revised pavement formulas not be driven ***totally*** by statistical considerations. Specifically, the functional forms of the new relationships should satisfy engineering principles and intelligent hypotheses of pavement behavior, and represent clear mathematical statements (in a dimensional way) of the contributions of different independent variables to pavement damage or performance.[5] Once the appropriate functional forms have been inferred, statistical techniques can then be applied to estimate the constants in the expression and assess its explanatory power.

Performance vs. Design

Another level of application of LTPP results that would benefit life-cycle costing is the reorientation of AASHTO and other procedures to focus on performance rather than design. Simply put, performance models predict how a structure will behave under actual or presumed conditions, whether or not these conditions are typical or meet design criteria. Design models, on the other hand, indicate the strength and materials properties with which a structure must be built to withstand certain loads or avoid a certain threshold of distress (e.g., the minimum acceptable level of PSI through the design life). What happens when the structure incurs or exceeds these loads or condition thresholds is not clear from a design perspective, but would be clear with a performance model. (This is a somewhat simplified comparison; additional facets of these two approaches will be given in the next section.)

In some respects the 1986 update of the AASHTO Guide represents a movement toward performance from earlier editions. Nevertheless, additional work remains to be done in several technical areas illustrated by the following examples:

- Including routine maintenance as a factor affecting pavement performance.
- Incorporating time-related changes in parameters wherever possible: e.g., water infiltration (and quality of pavement drainage); aging, creep, and other changes in materials properties; and the effects of existing damage on future performance.

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[5]Without the benefit of a good engineering hypothesis of appropriate functional forms of pavement models, computerized regression packages can produce overly cumbersome expressions involving many polynomial, logarithmic, and exponential terms and combinations thereof. These expressions are driven totally by the maximization of measures of statistical correlation, but often are otherwise impenetrable: Their mathematics are unrelated to physical aspects of pavement behavior and provide little insight to the relative importance of independent variables or the sensitivity of pavement performance to these factors. In some cases researchers have uncovered unexpected mathematical pitfalls within these needlessly complicated regression equations: e.g., hidden inflection points or zero points resulting in anomalous behavior or spurious results. To repeat a point made earlier: The quality of analyses of LTPP data will be an important determinant of their usefulness and application in practice.

- Accounting for variations in pavement conditions by location and over time, to quantify (1) inputs to reliability calculations, and (2) predictions of stochastic types of pavement distress (e.g., potholes, localized failures).

- Not only improving predictions of current pavement materials' performance, but also extending predictive capabilities to more advanced paving materials and new construction technologies. (This would entail related developments in several areas: e.g., analytic modeling, new types of nondestructive pavement measurements, and closer relationships between laboratory tests and field performance of pavement materials.)

Good performance models have robust functional forms that would not only include parameters to be explicitly measured by LTPP experiments, but also can accommodate (or be extended to cover) effects not immediately observed at the field sites. These latter influences on pavement performance could be assessed from companion state studies, or from theoretical considerations or engineering hypotheses of behavior.

Economic and Engineering Framework

Pavement design and analysis still takes place in the U.S. within a strongly engineering context. Even where type selection procedures are now employed by states, many key criteria governing the decision among alternatives are derived from an engineering, rather than an economic, perspective (e.g., the assumption of a fixed service life). The economic framework discussed in the 1986 AASHTO Guide is incomplete (as discussed earlier), and the actual design procedures discussed in Part 2 of the Guide are not developed fully according to the economic principles discussed in Part 1. A true life-cycle-based approach will require unification of Parts 1 and 2 of the AASHTO Guide, and pavement performance models satisfying economic criteria as well as valid engineering relationships.

To expand upon the discussion in the previous section, "performance" involves the prediction of pavement condition or service over time as a function of structural design, materials properties, construction quality, traffic loads, weather and other environmental effects, time-dependent changes in pavement properties (including damage, water infiltration, and materials changes such as aging), and maintenance history.[6] "Design" is a more limited concept, in that (1) it focuses on actions undertaken only at the beginning of pavement life, and (2) it often introduces somewhat arbitrary criteria to help fix the parameters of design: e.g., a service life of, say, 20 years, or a threshold of condition or damage that will not be exceeded.

These boundaries introduced by many design procedures inhibit life-cycle costing. Life-cycle cost analyses encompass actions throughout a pavement's life, not just at initial construction or a specific rehabilitation. Moreover, they do not require limiting assumptions regarding, for example, service life or thresholds on condition or damage. A life-cycle cost analysis does not require estimates of service life because other, cost-related criteria apply in evaluating pavement design or rehabilitation

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[6]This is obviously a general, somewhat idealized description that is beyond current analytic techniques. However, it provides a goal and a direction for future work in predicting pavement performance.

alternatives that may have widely varying service lives: i.e., the minimization of total discounted life-cycle costs, or the maximization of total benefits[7]. Similarly, arbitrary criteria governing pavement condition or damage (e.g., minimum acceptable PSI, or maximum acceptable roughness or cracking) in general are not needed, since the premise of life-cycle costing is that limiting thresholds of condition or damage can be evaluated on an economic basis. For example, the limiting value of PSI, roughness, or cracking (for example) would be established at that point where the marginal costs of additional damage would exceed the marginal costs of repairing the damage[8].

These arguments explain the statement earlier that good performance models can always be used for design, but design procedures cannot always be used to predict performance. Moreover, the broader analytic basis of performance models means that they can be applied to problems that go beyond pavement design: e.g., to studies of regulatory issues involving pavements (such as truck weight analyses or cost allocation studies), and to analyses of routine maintenance policy. The development of good pavement performance models therefore goes hand-in-hand with the incorporation of pavement analyses within a life-cycle cost framework.

Some additional comments on what would be entailed in moving toward a more economically based management framework for pavements follow:

- A total cost approach would require information on user costs as well as agency costs, particularly the variation in user costs as a function of pavement condition. User costs are now outside the scope of LTPP, but could be the subject of complementary research[9]. SHRP LTPP could, however, act as a catalyst for these studies.

- Data on untypical or unconventional pavement situations could be useful to assess life-cycle impacts more fully (e.g., light or moderate traffic on thick pavements, or heavy traffic on thin pavements, etc.). As things now stand, however, these unusual pavement cases are largely precluded from LTPP, not only because of the difficulty and expense of identifying and managing the larger number of sites implied, but also because the LTPP site selection entails

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[7]It is also possible to apply these economic criteria with constraints such as budget limitations, providing realistic criteria for pavement decisions.

[8]Certain "secondary factors" treated indirectly within the AASHTO Guide can also be incorporated directly within a life-cycle cost analysis by considering their impacts on pavement performance or costs.

[9]Recent research by the FHWA suggests little variation in user costs with pavement condition for the range of values normally encountered on high standard roads. However, data from developing countries suggest more substantial variations over a wider range of surface conditions. The threshold at which user costs begin to increase with further declines in pavement condition needs to be determined for various classes of highway, since that breakpoint is important to decisions on pavement investment and repair.

some censoring of allowable pavement age[10]. It would be beneficial to reconsider including some of these cases to anchor the life-cycle results at the limits of certain combinations of parameters such as age, thickness, traffic loadings, etc.

- Life-cycle cost analyses may be resisted because they are too complex. While it is true that a life-cycle approach considers factors beyond those included in a conventional pavement design calculation, this effort is more than repaid by the much wider range of pavement management issues that can be addressed: e.g., impacts of deferred maintenance, allowable vehicle weight limits, tradeoffs between capital investment vs. routine maintenance, staged construction options, and premium pavement warrants, in addition to most economical pavement design and type selection. Furthermore, although computer systems in our opinion allow easier, more flexible applications of life-cycle analyses, they are not absolutely required. For instance, a well designed and executed procedural manual can incorporate the all of the essential, desirable features of life-cycle analyses.

Implications for Highway Practitioners

Given all that has been said to this point, there are several implications of these near-term objectives for highway practitioners:

1. Since it is the GPS sections that will be set for monitoring first, data from these sections should be analyzed and made available as quickly as possible to support the states' implementation of type selection and life cycle costing within pavement management beginning in 1993. This does not mean that SHRP must have all analyses completed by 1993, since that would be unrealistic under current timetables. However, there should be communication between SHRP and the states regarding reasonable expectations of what results will be available when. (This is an excellent opportunity for states to follow SHRP Executive Director Damian Kulash's admonition at this workshop to make themselves heard, and to indicate how GPS results should support the new FHWA policy on pavement management.)

2. Technical results (e.g., in the form of new pavement performance models) will likely precede the development of formal economic procedures for life-cycle pavement costs. The performance models should anticipate a later economic framework, however. These developments will coincide with the

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[10]The censoring occurs by age of pavement: no flexible pavements built before 1970, and no rigid pavements built before 1965, are included in the GPS sections. The general comment offered at the workshop for this approach is that it will exclude "survivors" that would otherwise bias the statistical representation of pavement sections. The more basic question is, however: Is there anything unique in the design, construction, or use of these pavements that has enabled them to become survivors? Beyond this question, it is not clear why different ages have been as cutoffs for flexible vs. rigid sections, since this difference helps perpetuate the stereotype that rigid pavements perform longer than flexible pavements. This may have been true at one time, but is not necessarily so with recent improvements in materials and much more substantial pavement cross sections. It perhaps would be better simply to identify a range of flexible and rigid pavement sections--with no censoring by age--and let the LTPP results yield directly the expected lives of different flexible and rigid designs under different loads, environments, soil conditions, etc.

continuation of the shift from pure pavement design to more general predictions of pavement performance and costs that address several options: design, (re)construction, maintenance, and rehabilitation. It is what to do with the mature population of existing pavements, rather than the design of new ones, that will be the central issue in the future.

3. Conventional assumptions governing pavement design (e.g., a fixed service life of 20 years) can and should be replaced by economic criteria under life-cycle costing:

- Optimal economic solutions can yield the most efficient life with respect to prevailing traffic, regional and environmental factors, policies governing pavement design, maintenance, and rehabilitation, and relative costs.

- Strategies involving premium pavements may be called for in densely travelled routes or highways otherwise difficult to maintain or rehabilitate; conversely, strategies such as staged construction can be applied to lightly travelled roads. Different pavement policies by road classification or location can be evaluated using economic criteria.

- Current type selection procedures that involve fixed assumptions of initial pavement life or overlay service life may need to be reexamined in light of LTPP findings.

- Similarly, conventional wisdom on the "typical" performance lives of asphalt vs. portland cement pavements must yield to the much wider range of possibilities made available through new design concepts, construction practices, and materials characteristics, all of which can be considered with a life-cycle cost analysis.

- Budget limitations or funding biases inherent in various highway programs may continue to affect pavement management decisions, including those derived from life-cycle analyses. The use of such analyses can indicate, however, the extent of the distortion involved.

Implications for SHRP

The discussions earlier likewise present implications for SHRP, particularly in the type of results to derive from LTPP and the timetable by which they may be available:

1. Goals and criteria should be established regarding the type of pavement performance models to be produced from LTPP data, maintaining coherence and consistency in the form of the models and the trends in their predictions across the country.

2. Attention may need to be focused on early analyses of GPS data to serve the requirements for type selection and life-cycle costs by states beginning in 1993. These models should anticipate the eventual adoption of a life-cycle cost approach, and be able to assimilate SPS findings as well when they are available.

3. Performance equations should be able to integrate the effects of routine maintenance history; companion models should address new pavements and rehabilitated pavements in a coherent way. In our opinion, SHRP should maintain an open mind at this point as to whether "national" or "regional"

models are preferred. (If regional models are eventually adopted, however, there should still be some unifying concepts and general characteristics and approaches shared by the entire set of models.)

4. SPS data will need to be accumulated over a period of time before their performance trends become clear. These later analyses can benefit from the prior GPS analyses.

5. SHRP should continue to encourage the states to establish complementary test sections that go beyond the GPS and SPS programs. Also, the addition of some unconventional sections to the current LTPP pool would assist in later development of performance equations that are not biased by current design practices.

LONG-TERM OBJECTIVES, POSSIBILITIES, AND IMPLICATIONS

Conjectures about the long-term benefits of LTPP are necessarily speculative, particularly at this early stage. Nevertheless, some general themes can be offered to guide the direction of LTPP beyond the advances related to performance models and life-cycle analyses above. The empirical models needed for life-cycle analyses and type selection in the 1990s should be viewed as interim products providing immediate guidance to the highway industry. Longer term objectives should entail a better understanding of the causes of pavement performance and deterioration:

- LTPP data should be analyzed long-term in a mechanistic framework to fully address the traffic-related, regional, environmental, materials-related, and time-dependent contributions to damage. Mechanistic models would not necessarily be used in life-cycle cost procedures, since they are generally too detailed for economic or policy studies. However, they would provide technical depth and insight to support the simpler performance models used for life-cycle costs.

- If possible, the benefits of maintenance, rehabilitation, and drainage improvements should be captured within a mechanistic framework. Furthermore, this framework should address the interactions that occur among mechanisms of distress over time, and the influence of current damage upon rates of future damage. These capabilities would each represent considerable advances in mechanistic models over those in use today.

Similarly, better representations of the effects of traffic are needed, to which LTPP could also contribute:

- LTPP could help address contemporary concerns about new patterns of traffic loads: e.g., new axle configurations, tire profiles, higher tire pressures, etc.

- The possibility of monitoring dynamic vehicle loads on pavements (and resulting effects on pavement damage) at LTPP sites should be investigated.

- Ultimately, a more fundamental measure of mixed traffic loading should be sought to replace the AASHTO Equivalent Single Axle Load (ESAL).

CONCLUSION

This paper advocates a unified, coherent, innovative effort nationwide by LTPP toward pavement performance models for life-cycle costs. This objective implies common perspectives among LTPP contractors and sites toward both the collection of data and their analysis. It calls for new approaches in the analysis of LTPP data: e.g., to focus on models of performance rather than of design; to include the effects of routine maintenance, drainage improvements, and time-dependent changes in materials properties within these performance expressions; to anticipate the economic framework that will underlie the application of life-cycle costs to type selection and other pavement management decisions; and to use robust functional forms derived from engineering understanding of pavement behavior to guide statistical studies and to anticipate other parametric variations that may not be fully measured by LTPP. It regards GPS and SPS as two components of one experiment, not two separate experiments, and suggests ways that GPS and SPS results can be used to reinforce each other. These challenges will involve strong, steady management of the LTPP program, as well as depth of understanding of the many technical pavement issues involved.

Implicit in the many decisions surrounding LTPP is the type of role SHRP wishes to play in putting results into practice. Certainly LTPP will be the latest in a series of efforts in recent years (by the FHWA and NCHRP) to organize, analyze, and apply nationwide data on pavements. LTPP holds the promise of improvements in the AASHTO (and other) pavement equations, perhaps new load equivalency factors, and other valuable contributions deserving of credit. If, however, LTPP's contributions are viewed in a limited context, the program will represent a lost opportunity. This opportunity entails an early and firm commitment to life-cycle costs as the methodological approach by which pavement models should be developed and applied. It would call for the establishment of an economic framework within which these analyses should proceed. Although this framework and some related elements (such as road user costs) may be strictly outside the scope of LTPP, SHRP could exercise a catalytic leadership role in working with other organizations to bring these innovations about.

This proposal may appear idealistic and unrealistic at first glance. However, the example for this type of effort was in fact demonstrated thirty years ago, in the vision and conduct of the AASHO Road Test. Rather than simply updating the pavement methods of that time, AASHO embarked upon a revolutionary path whose results influenced pavement practice worldwide. A massive experimental and analytic effort was not the only product given to practitioners; more fundamental was a totally new concept of pavement serviceability, based upon the interaction between vehicle and pavement surface and the perceptions of road users. So innovative were the approaches, and so rich the data collected, that the AASHO results are still used in research studies today. This is the scale of opportunity that we believe is now available to SHRP in applying LTPP results to pavement life-cycle costs.

Session III

SYNOPSIS

LTPP DATA ANALYSIS-STRATEGIC OBJECTIVES

by Richard A. Lill
Representing American Trucking Associations, Inc.
Denver, Colorado
August 2, 1990

I am now retired, but I spent a number of years of participating in the development of the LTPP research program while highway engineer of the American Trucking Associations. During this time, there was a continual back-and-forth discussion about the best objectives for the research. It was clear throughout this period that each participant viewed the problem differently and, as a result, it took some time to arrive at a consensus.

This panel represents another aspect of the overall search for the highest priority objectives for LTPP program. In this case, it's an opportunity for those who are impacted by the research, but not a direct part of its conduct, to give their perspective on the questions they believe the analysis should address.

It is not too difficult to give the general objective that the trucking industry wants to see for LTPP program. First and foremost, the industry expects this research to provide significant help towards the construction and maintenance of pavements with the lowest life cycle costs. This will mean that the factors controlling pavement performance will need to be defined and quantified in cause and effect relationships. Once the basic goal is reached, subgoals such as improved design equations, viable performance equations, economic analysis techniques, etc. will follow.

To reach this goal, the analysis needs to have a place for the independent forces, both load and nonload, that can potentially cause pavement deterioration. Also, the dependent performance variables should be classified as distresses that are defined by measurable quantities. I believe that only in this way can the effects of the independent forces be uniquely quantified.

Similarly, the analysis needs to consider the potential impact of materials and construction variables on performance. These factors could not be made a part of the study as controlled variables, but their effect will likely exist in the experiments.

We also believe that another element may be present in some uses of the results that will flow from the study. This is the distinction that exists between performance equations and design equations.

For example, the AASHO Road Test analysis developed performance equations that related observed pavement behavior to the numbers and weights of different axle types. When converted to design use, however, the performance equations were adjusted with added thickness for a given traffic demand. More recent design techniques have introduced the concept of "confidence levels" that also provide extra thickness for a given traffic demand.

Design equations derived in this manner are sometimes used as performance equations, even though they are not. If they are used in this manner, there is usually an implicit assumption that the relative effects of different axle weights are independent of pavement strength, condition, or distress type.

This assumption has affected the trucking industry in a number of ways, and has resulted in the Trucking Research Institute sponsoring a partial review of the AASHO Road Test data to see if the axle load relationships were constant. The study concluded, for the single axle load data, that the axle load relationships were significantly variable across distress type, pavement condition, and thickness. A follow-up study of the tandem axle data is under way.

The trucking community recognizes SHRP and the LTPP program as an innovative and challenging research effort whose time has come. The industry supports its implementation; we look forward to improved information on a number of nagging issues, and we appreciate the opportunity to participate in this and other aspects of the program.

COMMENTS ON SHRP-LTPP DATA ANALYSIS FROM A REPRESENTATIVE OF THE AGGREGATE INDUSTRY*

Charles R. Marek

Technical Director, Vulcan Materials Company

Birmingham, Alabama

"The SHRP Long Term Pavement Performance (LTPP) program is a study of a carefully selected set of pavement and material types intended to extend the knowledge of the design and construction of pavements beyond current "state-of-the-art" limits. This will be accomplished by learning more about the interrelationships between (a) layer thickness, (b) loading, (c) materials, (d) soils, and (e) environment. The LTPP program is not a general study of common pavement types, nor is it a material evaluation program to evaluate specific materials to justify their use in pavement systems.

"The LTPP experiments and the data base resulting from the research program have been structured to provide data for (1) building empirical models based on observed performance and (2) calibration of mechanistic-empirical models that utilize responses calculated with mechanistic models as input to empirical distress models. The primary products expected from the LTPP program include: (1) better predictive models for use in design and pavement management, (2) better understanding of the effects of many variables on pavement performance, and (3) new techniques for design and construction."

It has been stated that <u>all</u> data elements that are significant to pavement performance will be included in the national data base being compiled. Unfortunately, this is <u>not</u> true, and therefore, the models to be

* Prepared for the Strategic Highway Research Program Summer Meeting, August 1-3, 1990, Denver, Colorado.

developed and the conclusions that will be drawn from the SHRP-LTPP study may be inaccurate and of limited value.

Because of time limitations I will focus my comments to one of several experiments being conducted in the LTPP program. This is the GPS "AC over granular base" experiment.

The "AC over granular base" pavement type is specifically defined as a layer of asphalt concrete material (hot-mix, dense-graded) placed over untreated granular base and subbase layers. More miles of this type of pavement than any other type of pavement have been constructed throughout the United States. As a consequence, the SHRP-LTPP study includes more test sections of this type than any other.

The basic inventory data being collected for the "AC over granular base" sections (which include the material properties of the structural components) are:

(1) Material type (crushed stone, gravel, slag)

(2) Percent compaction (AASHTO T-180)

(3) Percent passing No.200 sieve

(4) Percent passing No.40 sieve

(5) Percent dry density *in situ* at time of sampling

(6) Moisture content *in situ* at time of sampling

(7) Laboratory dry density (maximum)

(8) Resilient modulus of the minus 3/4 inch fraction of the base material.

The assumption has been made that these items will remain constant over the monitoring period, an assumption that may not be valid.

In addition, the following monitoring data (which include items that will change with time) will be collected:

(1) Distress, serviceability and skid measurements

(2) Traffic and axle load data

(3) Deflection testing results

(4) Pavement maintenance and cost

(5) Restoration and rehabilitation cost

The monitoring data will provide the historical data base required for development of relationships between distress, performance, traffic and axle loads, age, maintenance, and costs.

Material considerations have not been adequately addressed in most existing pavement design methodologies. A strong focus of the LTPP data analysis should be related to materials considerations and to correlation of physical properties of the materials of construction to the long-term performance of the pavements in which used. An inadequate/incomplete data base and analysis of measurements that do not properly represent the properties of the total *in situ* materials will result in flawed/erroneous relationships, models, and conclusions.

Sites selected for inclusion in the SHRP-LTPP study represent "state-of-the-practice" rather than "state-of-the-art" pavements. Current specifications and construction procedures of many state highway agencies do not reflect/utilize the best technical knowledge available. Technical knowledge already exists that will permit design and construction of better pavements than are being designed/constructed today and that have been designed/constructed in the recent past. Deficiencies can be found in (1) material gradation (top size/percent fines), (2) degree of compaction (T-99 versus T-180), (3) layer permeability, (4) system drainage (get the water out), and (5) other. For example, the granular base will contain greater than 7 percent minus No.200 fines, the fines may have some plasticity, the base will be inadequately compacted (<95% T-180), the maximum particle size will be 3/4 in. or 1 in. rather than 2 in. or 3 in., and a drainage layer of free-draining base (1000 to 5000 ft/day) will not be present in the pavement system. Most, if not all, sections that have been selected for SHRP-LTPP study have one or more of these deficiencies. Pavements designed and constructed to "state-of-the-art" concepts/procedures must be included in the SHRP-LTPP study to permit analysts to develop the desired predictive models and to limit unnecessary extrapolation of the data.

In the name of statistical efficiency and to reduce cost, several factors that impact significantly on pavement performance (and on the performance of unbound granular base materials in particular) have not been considered in the SHRP-LTPP study. Examples include: (1) particle shape (rounded versus crushed, angular), (2) maximum particle size (3/4 in. versus 2-3 in.) and (3) shear strength of the granular base. Certain nonsimilar aggregate materials (rounded gravel, crushed stone, and slag) have been grouped together in the SHRP-LTPP study to reduce the number of study variables and the number of test sections. This is a serious shortcoming of the SHRP-LTPP study.

All granular materials do not behave similarly in an unbound base application. The SHRP-LTPP data analysis should be performed to properly consider the physical characteristics/properties of the materials used.

A review of the test methods to be used for laboratory evaluation of base/subbase materials obtained from the LTPP field sections also reveals several deficiencies that, if not corrected, will preclude proper and accurate characterization of the base/subbase materials. The greatest deficiency pertains to evaluation of granular materials for (1) density, (2) resilient modulus and (3) permeability. Existing standard test methods that require the coarse fraction (plus 3/4 in.) to be removed and discarded from the test sample prior to test have been specified for material characterization. Since the plus 3/4 in. fraction of many *in situ* granular base materials could be 30 percent or more of the total base product, use of the existing standard test methods is inappropriate and the results obtained will not represent the *in situ* granular base material. All size fractions must be included in the test sample when significant parameters such as strength, density, and permeability are being measured. If corrections are not made, the SHRP data base will be seriously flawed.

If proper and accurate materials characterization is achieved, the aggregate industry will be receptive to the development and use of empirical models and mechanistic-empirical models for use in pavement design and pavement management. The industry hopes that such characterization will be forthcoming from the SHRP-LTPP effort, but is very concerned that noted deficiencies will preclude the desired characterization. As currently defined, the study will show performance differences between different test sections and attempts will be made by the analysts to correlate observed performance with various measured parameters, such as resilient modulus. Performance differences due to differences in strength properties rather than to differences in resilient modulus are likely to result. Correlation with a strength parameter, however, will not be possible since there is no strength test of any kind currently included in the LTPP evaluation program for granular base materials.

Predictive equations of various types are to be developed from the LTPP data and used as a basis for improved design methodologies. A design methodology that relies on measured physical properties for materials will be supported by the aggregate industry. The industry is opposed to the continued use of "coefficients" developed at the AASHO Road Test for pavement design.

The properties of many materials of construction, including granular base, are variable. Use of a constant coefficient (e.g., 0.14) for a given material type should not, but does, continue in many state highway agencies. Layer coefficients should be reevaluated, and a better design methodology should be developed and adopted. Development of a design methodology based on physical parameters for the materials of construction should be an objective of early SHRP-LTPP data analysis.

Pavement systems containing unbound granular layers have played and will continue to play an important role in pavements constructed in the United States. These systems are most economical, and when the component layers are designed and constructed to realize the best technical advantage of each component, these pavement systems exhibit long life and excellent performance.

In conclusion,

We must do the right things, and then we must do them right.

As Paul Benson said yesterday, "If the data being developed are wrong or if there is a significant amount of missing data, the design equations/ models forthcoming from SHRP will also be wrong." None of us want the products of SHRP to be wrong. Thank you.

LTPP DATA ANALYSIS: STRATEGIC OBJECTIVES
FHWA PERSPECTIVE

Paul Teng and Louis Papet
Federal Highway Administration

- Established at the peak of Interstate Program, the AASHTO pavement design methods have served us well.

- Through the revisions of 1972, 1981, and 1986, our approach has been to keep the basic design concept. However, many new items were added to the 1986 revision.

- As we are trying to implement the 1986 revision, we encountered many problems. While we are working to resolve some of these problems, no one really argues the fact that the many new items considered in the 1986 revision represent a general direction that we should work toward to improve the design methods.

- The 1986 revision opened a window for mechanistic-empirical design approach and also emphasized pavement management concept.

- For the longer term, we think the LTPP data should be used to develop and to refine the mechanistic-empirical/theoretical design approach.

- May be one of the problems with the 1986 revision is the fact we may have pushed the original AASHTO design methods to the extreme. We simply can NOT effectively add any more bells and whistles.

- This is NOT to say that FHWA is advocating the States to abandon the current or the conventional AASHTO design methods. What we are saying is that we need to look for a method down the road that can realistically reflect changes in traffic loading characteristics including load, tire pressure, and vehicle configurations; changes in construction materials and mix designs; and environmental variables.

- Under the new Federal Pavement Policy, the States working with FHWA field offices can gradually move into new design approaches without having to make an overnight change. They can stay with a conventional method until they feel comfortable with the mechanistic-empirical/theoretical approach.

- Specifically, we think the strategic objectives of the LTPP data analysis should be aimed at:

  1. Refining mechanistic structure models.

  2. Developing performance prediction equations for the types of distress which control pavement performance.

  3. Developing transfer functions which relate the stresses and strains calculated in the mechanistic structural model to actual pavement performance.

- For the near term, we think the LTPP data can certainly help the States to perfect or to organize their Pavement Management System (PMS). The uniform pavement evaluation and standard testing procedures and frequencies should be very beneficial, particularly to those States that are just getting into the PMS.

- We also see that as an overall by-product throughout the LTPP years will be improved training for the people who worked on the various activities. These people can become instructors as the State highway agencies implement LTPP findings into their program areas.

Session IV

SYNOPSIS

A PROPOSAL TO LEARN FROM WHAT WE ALREADY KNOW

by James L. Brown, P.E.
Engineer of Pavement Design
State Department of Highways & Public Transportation

"With a broad research project such as the AASHO Road Test, we know we will find many things, but the major part of the problem is to determine the value of the things we find.------

Our problem is to evaluate this material and determine how well it fits without experience and how well it agrees with other data available to us.------

These data (AASHO Road Test Data) can be combined with additional information from other sources.------"

R. A. Helmer, February 7, 1963

The above comments made by Mr. Helmer from Oklahoma are just as applicable to SHRP LTPP data in 1990 as they were in 1963 to the AASHO Road Test findings.

The primary objective of the Long-Term Pavement Performance Project of SHRP is to provide data and analysis to either create, calibrate, or verify a pavement design procedure for the nation's highway designers to use in designing new and/or rehabilitated pavements. "Create" implies that the data would be used both to determine the form of the design equations, as well as the coefficients in the equations. To "calibrate" implies only to determine the coefficients and to "verify" would be merely to confirm (and perhaps to revise) the model form and coefficients.

An examination of the incompleteness, bias, and other weaknesses in the SHRP LTPP data leads one to believe that it is incumbent upon the SHRP analyst to utilize every bit of existing knowledge that can be deployed to supplement the SHRP data. The following partial discussion of weaknesses in SHRP data is not meant to deprecate the SHRP effort, but merely to illustrate that the pavement design problem is large. More importantly, it is so large that we need to use everything available to adequately address it.

Difficulties with the LTPP data stem from three areas. First, <u>by its very nature</u>, the data will not be useful until a <u>long</u> time has passed. However, there is currently an urgent need for improved performance models, especially for rehabilitation performance. Secondly, many gaps exist in the data. Funding prohibited breadth in the experiments such that low traffic, surface treated roads; roads that have been rehabilitated twice or more; and many other types of pavements have been excluded. Within the experiments that were funded, gaps in the data exist because, for example, few thin pavements with heavy traffic or thick pavements with light traffic have been built. The third class of problems exist where some bias may have been introduced in the data. Bias to be expected might include things like the Northern States prohibiting, by specification, materials that are subject to freeze-thaw. Or, projects that failed early were reconstructed and not available for inclusion.

This paper proposes to have each state predict the dependent variables and distress histories for its GPS Sections using only prior knowledge. These distress histories would then be treated as performance data by the SHRP analysts to develop an initial set of performance prediction models.

Comparisons with this set of models and the first round of monitoring data (or a set of models from the first of data) should provide answers to many of Mr. Helmer's questions. If it is found that the states can predict distress with sufficient accuracy, this method can be used to fill gaps in data, gaps in full data sets, develop models for rehabilitation techniques, etc. If the current state of knowledge is of value, and if many of the experienced people that are making the predictions are approaching retirement, these predictions become a method for preserving the experience.

The paper gives specific recommendations as to what distresses to predict and general guidelines for an analysis procedure to follow.

EXECUTIVE SUMMARY

LTPP DATA ANALYSIS WORK PLAN

by

Dr. J. Brent Rauhut
Brent Rauhut Engineering Inc.
Austin, Texas

Dr. Michael I. Darter
ERES Consultants, Inc.
Savoy, Illinois

INTRODUCTION

The subject of this paper is the proposed work plan for Contract P-020, "Data Analysis", which is intended to serve as the primary vehicle for harvesting the results from the first five years of the SHRP LTPP studies and transforming this new information into implementable products. These early products will include:

1. A better understanding of the effects of a broad range of loading, design, environmental, materials, construction and maintenance variables on pavement performance.

2. Evaluation of and improvements to the models included in the 1986 AASHTO Pavement Design Guide.

3. Pavement rehabilitation strategies reflecting the results from analysis of data from GPS and SPS.

4. Data analysis plans for future analyses as time-sequence data for the GPS and SPS data enter the National Pavement Data Base (NPDB) and the National Traffic Data Base (NTDB) to offer opportunities for further insight and design improvements.

This project begins with development of analysis plans for this initial analytical effort. These plans are to be presented in early August 1990 to the highway community in a workshop, with input solicited and later integrated into final analysis plans. These plans are then to be implemented to produce the desired products by October 1, 1992.

This work effort is to be conducted by Brent Rauhut Engineering Inc. (Prime Contractor) and ERES Consultants, Inc. (Subcontractor). The BRE team under Dr. J. Brent Rauhut's leadership will be responsible for flexible pavement analyses, and the ERES team under Dr. Michael I. Darter's leadership will be responsible for rigid pavement analyses. However, analytical procedures used will be closely coordinated through discussions and decisions by an "Analysis Planning Group" to consist of key personnel from both companies and from SHRP and P-001 staff. Planning and progress will also be reviewed and observed by an expert task group on LTPP Experimental Design and Analysis. These activities will also be closely coordinated with other contractors conducting analysis for SHRP LTPP through periodic meetings of a Data Analysis Coordination Group. The principal investigators will also work closely with Mr. Jim Sherwood at SHRP-DC and Dr. William O. Hadley of the P-001 staff. The research teams of BRE and ERES are also supported by statistical consultants, Dr. Olga Pendleton of Texas Transportation Institute and Dr. Sam Carmer of the University of Illinois. Dr. Robert L. Lytton of Texas Transportation Institute will participate during the early planning for the data analysis, during workshop discussions, and while planning for the future data analysis. Dr. Anastasios M. Ioannides of the University of Illinois will offer strong support in mechanistic modeling and utilization of dimensional analysis in simplifying equation forms to be considered.

Doctors Rauhut and Darter, and the research staffs of BRE and ERES, have worked together on three previous projects of national importance that contributed to the experiment designs, plans, and implementation of the LTPP. They have an established working relationship and a strong desire to bring these plans to fruition.

GENERAL PLANS TO DEVELOP PRODUCTS

The purpose of this section of the paper is to explain briefly how the implementable products listed above will be obtained. More detail as to specific activities will be discussed later in the paper.

A better understanding of the effects of a broad range of explanatory variables on pavement performance is to be obtained through state-of-the-art statistical analyses, which are often called "Sensitivity Analyses" by engineers. This term implies that the sensitivity of the dependant variable (e.g., rut depth, area with moderate level alligator cracking, etc.) to variations in explanatory variables (e.g., layer thicknesses, layer stiffnesses, mean temperatures, traffic, etc.) over reasonable ranges will be identified. Another explanation would be that the relative significance of variations over reasonable ranges of the explanatory variables to some performance measure for the pavements will be identified. For each type of pavement for which there is sufficient data, sensitivity analyses will be conducted individually for each distress type or performance measure that is itself to be considered significant. The results will be graphically and numerically displayed for ready interpretation of the relative importance of the various materials, environmental, or pavement structure characteristics to the resulting pavement performance. This information may then be used to evaluate and/or modify the emphasis in specifications and standard design procedures to progress toward the construction of pavements that last longer and are more cost-effective.

The Highway Community is well aware of the many limitations of the original AASHTO Road Test and of the resulting equations that have been revised many times and now appear in the 1986 AASHTO Design Guide. The comparison of predicted serviceability loss from these design equations to measured serviceability loss from the NPDB will provide extremely valuable insight to us as to their precision. The primary limitations to this work effort will be the lack of precision in the estimates of ESAL's from historical traffic data, and the lack of measured serviceability data at the time of original construction. As to the ESAL estimates, it is critical that the State Highway Agencies do their very best in the development of the historical data, and that the SHRP Regional Coordination Offices and the P-001 staff do their very best in interpreting the data to arrive at final ESAL estimates. With regard to the initial PSI values, the Regional Coordination Offices and the State Highway Agencies will need to carefully consider available information on specific projects and any research studies aimed at identifying PSI values for original construction to assist the P-020 contractor in making appropriate selections. The evaluation of the design equations will be heavily dependant on the accuracy with which the initial PSI values are estimated.

The approaches to improving the AASHTO Design Equations may range from adjusting the coefficients on existing equations to nonlinear multiple regressions to produce better equations, and combinations in between. The choice will depend on information on relative significance of various explanatory variables to PSI loss from the sensitivity analyses, the results of evaluating the residuals from the evaluation phase, and other statistical studies. Because there is a general expectation that other explanatory variables (e.g., subgrade resilient modulus) may be found to be significant and that revised equation forms may better fit the data, the best estimate at this point in the analysis planning is that nonlinear regressions will be conducted to develop new and improved predictive equations that include mechanistic and other variables.

The development of pavement rehabilitation strategies will begin with the establishment of State Highway Agency priority needs in current practices. It is expected that the sensitivity analyses on experiments GPS-6A and GPS-7A will provide predictive equations for asphalt concrete overlays of asphalt concrete and rigid pavements (probably only in the wet zones for rigid pavements), as well as important information on the relative significance of the explanatory variables. The predictive equations resulting from the sensitivity analyses for GPS-1, GPS-2, GPS-3, GPS-4, and GPS-5 are expected to provide a basis for a "Do-Nothing" strategy. The AASHTO overlay equation will be evaluated through comparison to measured performance from GPS-6A and GPS-7A. Available knowledge will be accumulated from other studies (FHWA-ERES rigid and flexible pavement overlay studies, improvements of the AASHTO overlay procedures, demo projects, etc.). All of this information will be brought together to: 1) Develop procedures for pavement evaluation, 2) develop procedures for predicting future performance with no rehabilitation, 3) develop criteria for selecting maintenance/rehabilitation strategies, and 4) development procedures for predicting performance after rehabilitation. Because of limitations on available rehabilitation data from the GPS, this activity must necessarily draw information from other sources in order to produce the desired products.

The development of future LTPP data analysis plans must consider carefully the considerable differences between the limited data available for the P-020 effort and the much better data base of the future that will include time-sequence data (as opposed to the "snapshot" data available now) as well as SPS data. The P-020 effort will be evaluated to determine the effectiveness of the procedures and the adequacy of the results. Working closely with SHRP, P-001 staff, and various representatives of the Highway Community, future LTPP data analysis objectives and requirements will be formulated and plans developed for the future analyses to satisfy these objectives and requirements. The results of this activity will be presented and discussed at a second data analysis workshop in 1992.

While not included in the contract scope as presently funded, BRE plans to pursue development of load equivalence factors for rutting, fatigue cracking, and roughness for flexible pavements, working interactively with Dr. Gil Baladi and the Michigan State University staff, who are also engaged in data analysis. The tentative agreement involves the generation of a data set of mechanistic responses for all flexible GPS pavements by Dr. Baladi, using his MICHPAVE finite element program. These mechanistic responses will be included in the multiple regressions for the sensitivity analyses to produce mechanistic-empirical equations that predict the occurrence of these distresses. These mechanistic-empirical distress models will then be furnished to Dr. Baladi, who will insert them into the MICHPAVE program and generate a "computer road test", with specific axle loads to be applied on each of some 864 or more test sections. The resulting predictions of distress will then be utilized by BRE for the development of load equivalence factors for the three distress types identified above. The realization of this extra work effort will be naturally dependent on resources, but the research team will endeavor to accomplish it, either within existing resources or with other support that may develop.

A similar effort may also be accomplished by ERES for rigid pavements, using mechanistic-empirical distress models for key distress types.

SENSITIVITY ANALYSES

While the primary objective of the sensitivity analyses is to establish the relative significance of the explanatory variables to the performance of the pavements, the procedure selected necessitates the development of multiple regression equations upon which the sensitivity analyses are conducted. This is fortuitous because these equations have enormous value of their own. Performance prediction equations are critically needed for pavement management system and for use in design. These equations may serve as design checks in the next edition of the AASHTO Design Guide, and may represent the beginning of a desirable initiative to design pavements to resist all common forms of distress in the future.

This activity must begin with an evaluation of available data in the NPDB. Mr. Gary Elkins has discussed briefly the data available for the GPS test sections in his executive summary entitled "The GPS Experiments as Implementated". The research team will, upon receipt of the first installment of data, conduct studies to indicate what data elements are represented for individual test sections, numbers of test sections having specific data elements by experiment, and the distributions of specific data elements within the data base.

Using knowledge from previous studies, it will be necessary to identify data elements that are considered to be necessary for meaningful analysis and to work with the Regional Coordination Offices and the State Highway Agencies to obtain necessary data wherever possible. In this regard, all concerned need to remember that a test section is virtually useless unless the data is adequate for analytical purposes.

While the exact techniques to be applied are still subject to further study, the SAS statistical package will be used. This sophisticated statistical analysis system has a variety of options that may be employed. Whichever approach is selected, the principal component method for detecting collinearity and influential observations will be carefully applied to produce robust models. After the predictive models have been developed, studies of the residuals will be conducted to evaluate their predictive capabilities and to determine whether new models with different equation forms should be developed.

In order to avoid the possibility of overlooking explanatory variables that could be relatively significant, it is expected that twenty or more variables must be considered for each distress type for each pavement. In order to simplify the development of equations and their future application, various transformations will be considered to combine the explanatory variables into "clustered terms". Prior knowledge and dimensional analysis will be used to combine these variables in mechanistically sensible and logical combinations.

Those of the readers that are familiar with sensitivity analyses will realize that they are most effective when applied to designed experiments that result in a data base whose data elements meet the statistical assumptions common to such applications. Although the GPS experiments were designed to the extent possible, the resulting GPS sampling plans reflect many gaps in the data and the distribution of values for various data elements are not all ideal. This does not mean that reasonable results cannot be obtained, but it does mean that the best efforts of the engineers and statisticians engaged in this activity will be required.

Once the research teams are satisfied with the predictive equations developed for the sensitivity analyses, these analyses will be conducted separately by distress types common to a particular pavement type and for which sufficient data is available for analysis. The outputs from these analyses are expected to be:

1. The significant independent variables affecting each distress.

2. An indication of how strongly each of these variables, singly and in interaction with others, affect the chosen distress.

3. A regression equation relating the distress variable to the significant independent variables.

4. The measure of the predictive accuracy of the above regression equations.

The key performance measures (distress types and roughness) to be considered include the following:

1. Pavements with asphalt concrete surface layers (including overlays of flexible and rigid pavements):

   - Alligator cracking
   - Transverse cracking
   - Rutting
   - Raveling/Weathering
   - Roughness

2. Jointed Concrete Pavements (including unbonded JCP overlays):

   - Transverse cracking
   - Longitudinal cracking
   - Joint faulting
   - Joint spalling
   - Pumping
   - Roughness

3. Continuously Reinforced Concrete Pavements:

   - Localized failures (punchouts, transverse ruptured steel, etc.)
   - Roughness
   - Pumping

EVALUATION OF AASHTO DESIGN EQUATIONS

This activity is fairly straightforward once the Present Serviceability Index at some point in time and an associated level of accumulated ESAL has been established for each test section, and an estimated initial PSI level has been selected. PSI will have to be calculated, using the measured values of roughness and other observed values in the relationships for PSI.

The research team tentatively plans to rearrange the design equations to predict serviceability loss, rather than numbers of ESAL to produce a specified loss in serviceability. This appears to be more consistent with the nature of all of the other predictive equations and with the concepts of predicting performance itself. It would, of course, be possible to evaluate the equations in the form appearing in the design guide.

Once the required data elements from the NPDP have been established and the PSI loss calculated, comparisons will be made between measured and predicted PSI loss for each test section for which sufficient data is available. Predicted versus measured PSI losses will be graphically displayed for various groupings and test sections (environmental zones, AC or PCC thickness levels, ESAL levels, etc.). An analysis of the residuals will be conducted to identify possible deficiencies in and improvements to the design equations.

Utilizing the information from the comparative analyses and the analysis of residuals, it will be determined which of the following cases apply:

1. Other independent variables and/or interactions are needed in an equation.

2. A revised functional form is needed.

3. Revised functional form and additional variables and interactions are needed.

4. Refinements in selection or calculation of input variables is needed.

Recommendations will be developed for revising the design equations.

IMPROVEMENT OF AASHTO DESIGN EQUATIONS

The results from the sensitivity analyses and the evaluations of the predictive capabilities of the AASHTO design equations are expected to offer specific identification of:

1. Relative significances of the various explanatory variables to the predictions of serviceability loss and key distress types.

2. Explanatory variables of significance to serviceability loss that are not included in the AASHTO predictive equations. Also, types and severities of distress types that cause loss of serviceability.

3. Sets of conditions for which the AASHTO equations are relatively precise and those that appear to lead to poor predictions.

4. Possible realignments in emphasis of significant explanatory variables in the equations.

5. Insight as to what approaches to improving the AASHTO equations should be pursued.

Using the information listed above, the research team will select procedures for improving the design equations. As discussed previously, this could include any of the following five possibilities (and perhaps others):

1. Development of adjustment equations to calibrate design equations.

2. Maintain current equation forms and regress the equations against available data to develop improved coefficients.

3. Maintain general equation forms, add additional explanatory variables, and regress to develop improved equations.

4. Experiment with new equation forms, using significant explanatory variables, to develop improved predictive equations.

5. Conduct nonlinear regressions with equation forms and significant explanatory variables to develop new and improved predictive equations.

Assuming that development of new equations will be indicated, it will be very important to have some reliable means of evaluating these equations. Some possibilities include utilization of the data from international sources or from other US data bases. However, the most direct approach appears to be utilization of perhaps 80% of the data base for developing the equations, and the other 20% for evaluating the resulting equations. The research team plans to develop the equations five times, utilizing different combinations of the data base for equation development, and utilizing a different set of data each time for evaluation. As a result, all of the data will have been utilized in developing the equations, and all of the data will have been utilized for checking out the equations. The residuals from each of these five equations will be studied, and appropriate adjustments will be made for the final equation.

The results from this activity are expected to be improved design equations based on Present Serviceability Index. The research team could be easily influenced to developed these improved design equations in terms of roughness, which is the value directly measured by State Highway Agencies. PSI as it was developed at the AASHTO road test carries with it the limitations of the road test, and may or may not be a logical primary design basis for the future. Serious consideration of whether serviceability or roughness should control design in the future, or whether it should be an array of significant distress types individually, or both, is certainly an appropriate topic for discussion by the highway community.

DEVELOPMENT OF PAVEMENT REHABILITATION STRATEGIES

It has been recognized from the beginning of the planning effort for the LTPP studies that the most crucial outputs from this research effort would be: 1) a much better understanding of the effects that may be expected from the various maintenance and rehabilitation treatments that are being employed and 2) models that would predict performance with and without maintenance and/or rehabilitation. It was also quite clear that the data for these studies would not become available as rapidly as they would be needed. The approach proposed by the research team is to take full advantage of the limited data available and knowledge from other studies to produce a maximum of practical guidance to engineers responsible for maintenance and rehabilitation decisions. Guidance is needed on whether to treat or do nothing at any point in time, at what point in a pavement's life and/or deterioration cycle to intercede with some treatment, what may be expected to be the results from specific treatments, and how to sort out the potential strategies and arrive at the best decisions. These are the challenges for this task, and relative success will offer major economic benefits.

The research team must keep the long-term objectives in mind as they work toward accomplishment of the short-term (or early) objectives. Some of the capabilities to be sought in the future, and to be partially achieved during this project, are as follows:

1. The ability to predict what will happen to the pavement if nothing is done (the "do nothing" alternative). This implies the ability to predict the future deterioration of the existing pavement under the expected traffic and within the environment in which it has been placed, assuming that no maintenance or rehabilitation work is performed.

2. Criteria and procedures to help in the selection of "feasible" maintenance/rehabilitation strategies, given the expected future "do nothing" pavement deterioration and any combination of existing pavement conditions and anticipated future needs. ("Feasible" in this context implies strategies that can be accomplished within the various budget, construction and traffic control constraints that exist for a project).

3. The ability to predict the performance of the feasible maintenance and/or rehabilitation strategies so that their future service life and costs can be estimated and compared. This will provide a partial basis for choosing among alternative strategies.

During the time frame of this contract, quite a lot of data will be available, but quite a lot will not. The primary data source will be the General Pavement Studies. Considerable data will be available from GPS-1 through GPS-5 for the evaluation of factor effects on new or reconstructed pavements, and for the development of limited predictive models during the sensitivity analyses. Very valuable data will also be available from GPS-6, GPS-7, and GPS-9. GPS-6A and GPS-7A will include overlays with a considerable age distribution, but will generally have limited information as to the condition of the pavements prior to overlay.

The potentially most valuable studies for future rehabilitation strategies are SPS-5, SPS-6, SPS-7, GPS-6B, and GPS-7B. However, construction of the large majority of these will occur during the same period that these data analyses will be underway, so little performance data may be expected, except for test sections that experience early distress such as reflective cracking or more serious deterioration that might be classified as "early failures".

The maintenance cost effectiveness studies, SPS-3 and SPS-4, will also be constructed early in the lifetime of this contract, so all that can be expected from them will be occurrences of early deterioration for specific treatments under various sets of conditions, and perhaps some construction data that might prove valuable.

The construction of the SPS-1, SPS-2, and SPS-8 projects will not occur in time for useful input to these initial studies. Fortunately, ERES Consultants, Inc. has been conducting broad performance studies for the Federal Highway Administration and elected to use the data collection procedures that had been developed for LTPP. These data and the results from these studies will also be considered during this research. The research team will also be alert for other study results that may be logically considered to expand our inference space for meeting the task objectives. The results from NCHRP 1-26 calibration of mechanistic models will be considered.

The research approach will be to gather all of the data of value that can be located by the research team, to glean every bit of information possible from this data, and then to apply the expertise and experience of the project team to develop practical procedures and guidelines for use in making maintenance and rehabilitation decisions that reflect the new state-of-the-art derived from these studies.

FUTURE LTPP DATA ANALYSIS PLANS

As the contract P-020 data analysis for early products from LTPP will be the first of a number of analytical efforts as the data base grows, the highway community rightfully expects that one of the major products from this effort will be detailed procedures for future analyses reflecting the experience from these. The project team understands that this contract effort represents a "Pilot Analysis", so they will keep in mind the necessity for optimizing the analytical procedures for the future as they conduct the tasks under this contract.

As the analytical procedures adopted should reflect the direction that the AASHTO design procedures are expected to grow or progress, the highway community needs to consider this as they interact with SHRP and the contractors during this early analysis period. For instance, should the Present Serviceability Index as developed at the original AASHO Road Test continue as the sole basis for design of pavements, or should other distresses or performance measures that initiate rehabilitation or major maintenance be considered also? Would it be appropriate to utilize roughness measurements in lieu of PSI, considering that roughness is by far the most significant variable in the PSI equations that resulted from the regressions on AASHO Road Test data? Is it logical to represent all pavement distress by a single dependent variable, when rehabilitation often results from cracking and other distress failures? Should the highway community be striving toward a design procedure that considers all distress types that may affect pavement performance? In short, recommendations for future analyses of LTPP data should consider a coherent policy reflecting both the results of the studies underway and highway community needs and preferences.

Plans for future analysis will include full consideration of the improvement of mechanistic-empirical equations that utilize individual and combinations of mechanistic and empirical variables, as well as the development of empirical equations where they are found to be more practical.

DEVELOPMENT OF IMPROVED LOAD EQUIVALENCE FACTORS

The need for improved load equivalence factors (LEF's) has been recognized by all concerned with the planning and design of the LTPP experiments. However, plans to achieve these results have been frustrated because the development of LEF's requires controlled traffic on separate test sections, while the LTPP studies are based on inservice highways with mixed traffic. The possibility of a multitude of road tests was discussed early in the planning effort, but this is obviously impractical due to the massive costs. Consequently, the only apparent possibility that has surfaced is to utilize the NPDB to calibrate mechanistic-empirical models, and to utilize the calibrated mechanistic-empirical models to generate "computer road tests" for a variety of climates, subgrade conditions, and representative sets of single and tandem axle loads.

BRE and a team from the Texas Transportation Institute conducted such computer road tests in the early 1980's to develop load equivalence factors for various flexible pavement distresses in support of the FHWA cost allocations studies. These road tests included a subtotal of 864 test sections, representing four environmental regions, three subgrade moduli, three thicknesses of surface coarse, three structural numbers, and eight load levels (four single axle loads and four tandem axle loads). Multiple regressions were conducted on the 864 sets of flexible pavement distress predictions over a broad range of conditions to develop predictive damage models. For these studies, the same damage function used for the AASHO Road Test (with ρ and β as parameters) was used. Seven equation forms were considered for the regressions of ρ and β, and the one offering the best statistical fit to the data was selected. The equations for ρ and β included the same independent variables as those from the road test, except that the subgrade modulus of elasticity was added. LEF's were developed independently for rutting, fatigue cracking, and serviceability loss.

Drs. Rauhut, Darter, and Lytton did not make strong claims for these load equivalence factors, primarily because the data available for calibrating the VESYS III-B model utilized was very limited. The concepts were considered to be an important development, however, and the approach deemed to be viable in the absence of billions of dollars and many years of time for constructing and conducting a multitude of road tests. The availability of orders of magnitude of additional data for developing the distress equations using the NPDB represent a major change in the conditions for applying this concept. Consequently, it is believed that LEF's from this effort may be reasonably reliable, and the resulting data base from the computer road test could perhaps serve the highway community as a basis for developing other concepts for allocating damage to various vehicle classes for the future.

As mentioned earlier, the development of LEF's was not included in this contract, but represents a very desirable objective for the highway community. It is generally recognized that these early analysis efforts are not heavily funded, so the research staff (including in this case ERES and MSU staff) can only express a commitment to accomplishing this if at all possible within existing or other resources that may be forthcoming.

PRACTICAL LIMITATIONS TO DATA ANALYSIS

The emphasis of this paper has been toward what can be accomplished, rather than what cannot because of limitations in the data base at this early point in the long-term pavement performance studies. However, it would be foolish to write this paper without some discussion of what may not be expected as early results. None of the early results may be expected to exceed in quality the adequacy of the data base upon which they are developed.

There will be a substantial amount of inventory data available, and much of the remaining data of this type will come from the material sampling and testing. These data will represent a substantial portion of the significant explanatory variables needed. However, traffic data, which is critical to these studies, will only be available at limited reliability, and this is a major weakness that will have to be overcome as best as possible. The historical traffic data will be of highly variable quality, and we will not have enough current traffic data within the contract period to do a thorough job of backcasting. As traffic data is critically important, all concerned should encourage the State Highway Agencies to do the best they can in developing the historical traffic data and to expedite current traffic measurements to obtain as much of that as possible. SHRP and the P-001 staff need to plan and implement efforts for back-casting to improve the estimates of accumulated ESAL's as much as possible.

There will be at least one round of distress data (including roughness from profile measurements) to provide performance information for the studies. In addition to this, the condition of the pavements following construction may be estimated, perhaps at reasonable confidence levels. It is commonly known that it is not possible to identify nonlinear relationships with only two points, especially if one of those points is approximate. However, it has been shown in previous studies that it is possible to do a reasonable job of this, considering the distribution of pavement ages and application of knowledge that we already have and appropriate statistical procedures and logic tests.

We expect to have environmental data, deflection data, and skid resistance data by June 1991. Some historical maintenance data may be available, but this will likely be limited. Historical rehabilitation data for GPS-6A, GPS-7A and GPS-9 should be available from inventory data.

In summary, it has always been a goal to provide some early results with limited data, and the overall picture looks promising, as long as the limitations implied when seeking short-term results from long-term studies are kept in mind.

MECHANISTIC CALIBRATION AND REVISION OF THE AASHTO DESIGN EQUATIONS

A working paper
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TABLE OF CONTENTS

		Page
	ABSTRACT	1
1.0	INTRODUCTION	2
2.0	BACKGROUND AND GENERAL OBSERVATIONS	2
3.0	MECHANISTIC BASED APPROACHES	3
4.0	BENEFITS OF THE MECHANISTIC CALIBRATION/REVISION OF THE AASHTO DESIGN EQUATIONS	4
	REFERENCES	10

ABSTRACT

This paper highlights the procedures and benefits of the mechanistic evaluation, calibration and revision of the AASHTO design and performance equations. The procedures were proposed to be used in contract P-020 "Data Analysis" of the long term pavement performance (LTPP) studies of the Strategic Highway Research Program (SHRP).

MECHANISTIC CALIBRATION AND REVISION OF THE AASHTO DESIGN EQUATIONS

1.0 INTRODUCTION

This technical paper highlights the procedures and benefits of the mechanistic evaluation, calibration and revision of the AASHTO design and performance equations. These procedures were proposed to be used in contract P-020 "Data Analysis" of the Long Term Pavement Performance (LTPP) studies of the Strategic Highway Research Program (SHRP).

The goal of the LTPP studies established by the "Strategic Transportation Research Study" and adopted by the Advisory Committee on Pavement Performance is:

"TO INCREASE PAVEMENT LIFE BY INVESTIGATION OF VARIOUS DESIGNS OF PAVEMENT STRUCTURES AND REHABILITATED PAVEMENT STRUCTURES, USING DIFFERENT MATERIALS AND UNDER DIFFERENT LOADS, ENVIRONMENTS, SUBGRADE SOIL, AND MAINTENANCE PRACTICES."

2.0 BACKGROUND AND GENERAL OBSERVATIONS

Empirical pavement design procedures are derived from experience or observation alone, often without detailed consideration of system behavior or pavement theory. Empirically derived relationships defining the interaction between performance, load, and pavement thickness for a given geographical location and climatic condition are the basis for many existing design methods. These methods or models are generally used to determine the required pavement thickness, the number of load applications required to cause failure or the occurrence of distress due to pavement material properties, subgrade type, climate, and traffic conditions.

One advantage in using empirical models is that they tend to be simple and easy to use. Unfortunately, they are usually only accurate for the exact conditions for which they have been developed. They may be invalid outside of the range of variables used in the development of the method. Further, engineering interpretations of most purely empirical equations are meaningless and/or misleading. The AASHTO, Corps of Engineers, Louisiana, and Utah design methods are among a large family of empirical pavement design methods that were primarily developed on the basis of observed field performance.

The AASHTO pavement design methods for both rigid and flexible pavements are based on results obtained from the AASHO Road Test conducted in the late 1950's and early 1960's in northern Illinois. The methods are empirical and relate pavement performance measurements and the loss of serviceability directly to the traffic volume and loading characteristics, roadbed soil parameter (resilient modulus or coefficient of subgrade reaction), pavement layer material characteristics (layer coefficients, or modulus of rupture), and environmental factors that were present at the road test. The methods (design equations) have been generalized to make them applicable to broader sets of design variables. The original design equations were issued in 1961. The 1986 AASHTO Guide for the Design of Pavement Structures follows the same basic design approach with some improvements in the flexible pavement design.

Recently, the AASHTO design equations were enhanced to include design reliability, material variability and construction quality. Further, the pavement performance period can be adjusted for environmentally-induced losses of serviceability such as frost heave.

The present AASHTO model is deficient because it is directly applicable only to the northern Illinois climate and the specific subgrade and materials used for the pavement/subgrade structure. Further, it is based on an accelerated procedure for accumulating traffic, which considers only two years of environmental effects in conjunction with several years of traffic load. These deficiencies have been reduced to some extent by the incorporation of the experience of several State Highway Agencies (SHA) with pavements located in different climatic conditions and with different materials and traffic.

Various important pavement design concepts were identified at the AASHO Road Test including the influences of traffic loads and repetitions upon design thickness, and the serviceability-performance concept. The latter concept provided a quantifiable means for defining failure conditions based on a user-oriented definition rather than one based primarily on structural failure.

For overlays, the AASHTO method requires the estimation of remaining life factor of the existing pavement. This factor can be estimated using various procedures presented in the 1986 AASHTO design guide. The experience of many State Highway Agencies has indicated the inadequacy of the overlay procedure due to the lack of guidance to estimate the remaining life factor.

Since the AASHO Road Test, many other pavement performance and distress prediction models have been developed for both flexible and rigid pavements and have been incorporated into various design models. Each model was developed by using a specific pavement database and model development techniques and is, therefore, subject to limitations and generally applicable only for specific conditions. None of these models were developed on the basis of mechanistic response of the various pavement layers to the applied traffic load. Hence, a new and innovative approach needs to be developed whereby observed pavement distresses are directly related to the mechanistic responses of the various pavement layers due to a passing wheel load.

3.0 MECHANISTIC BASED APPROACHES

A proper pavement performance prediction model that yields the proper engineering interpretations must be based on the mechanistic responses (stresses and strains) of the pavement structure due to a passing wheel load. The performance models can be obtained using two approaches, statistical and theoretical. The statistical approach consists of relating the calculated pavement mechanistic responses to the observed pavement distresses (this is called mechanistic-empirical models). The theoretical approach, on the other hand, models the pavement structure and its boundary values, and the load related distresses (e.g., rutting, alligator cracking for flexible pavements) using various available theories. The main disadvantage of the theoretical approach is that it tends to be complicated and it requires substantial material and boundary value inputs that are not available or cannot be obtained by most State Highway Agencies (SHA). The main advantage of the mechanistic-empirical models is that the required inputs are readily available in most SHA. Hence, such models can be developed using data from the National Pavement Performance Database and/or any other pavement management system database that contains pavement distress data coupled with the outputs of the mechanistic analysis of the pavement structures in question.

After developing the performance models, the AASHTO design equations can then be evaluated, calibrated and revised. To optimize the benefits of such evaluation and revision, the procedure(s) must be capable of properly investigating the validity of the various concepts and assumptions embedded in the AASHTO procedures. These concepts and the benefits of the mechanistic-empirical evaluation and revision of the AASHTO performance models are presented in the next section.

4.0 BENEFITS OF THE MECHANISTIC CALIBRATION/REVISION OF THE AASHTO DESIGN EQUATIONS

To optimize the benefits of this study, the evaluation, calibration and revision procedures of the AASHTO design equations must be capable of investigating the validity and accuracy of the various assumptions and concepts embedded into the equations. These include:

1. The concept of layer coefficient - Are the existing nomographs relating material properties (e.g., modulus) and layer coefficients valid and accurate? What are the engineering interpretations of such correlations? For example, for similar pavement performance, the AASHTO design equations assume that if the layer coefficient is increased by a factor of 2 then the thickness of the layer can be halved. That is the problem of a weak material can be solved by increasing its thickness. From the engineering point of view, decreasing strength yields higher strains (higher damage) and hence, higher rut potential. Hence, using weaker material (for economic reasons) may not be economical after all.

2. The concept of drainage and drainage coefficients and their effects on the pavement design outcome - In this regard, the 1986 AASHTO design guide allows the use of thicker layers to solve drainage problems. That is, bad drainage implies lower drainage coefficient and hence, a thicker pavement layer. This concept/problem needs to be investigated along with the values of the drainage coefficients. Only after obtaining an accurate solution of the problem, the highway engineer can make a correct decision regarding the cost (a thin layer with drainage or a thick one without drainage) of the pavement structure and its expected performance.

3. The concept of Equivalent Load Factor (ELF) - In this regard, two issues must be considered:

   a) For a given pavement section, is the value of ELF constant with time?. That is, since pavement deteriorates with time and its effective structural number, thickness, or structural capacity decreases with increasing traffic, should the value of ELF increase? Or, is the value of ELF representative of the average value during the life of the pavement? If this is so, what is the validity of the AASHTO ELF since it was developed based on only two years of environmental damage? That is, should the ELF of two similar pavement sections located in different environmental regions be the same?

b) For a given pavement section and a given truck type and load, is the value of ELF relative to roughness the same as that relative to fatigue? Stated differently, is the relative roughness damage delivered by a given truck equal to the relative fatigue damage delivered by the same truck? If not, then what values of ELF should be used for the various distress prediction models?

4. The concept of loss of serviceability due to environmental factor (i.e., swelling soil and frost heave) being additive to that due to traffic - In this regard, can the problems of swelling soil and frost heave be overcome by providing thicker PCC or AC surfaces as implied in the 1986 AASHTO design guide?

5. The validity of the overall statistical correlation of each equation - That is, the engineering interpretations of the equations need to be fully explained so that a proper diagnosis of the pavement problems can be obtained.

6. The concept of PSI and roughness - The AASHTO equations are based on the pavement serviceability index (PSI) which is highly correlated to pavement roughness in terms of the average slope variance in the wheel paths. Patching, cracking, and rutting have minor effects on the PSI. Most State Highway Agencies use roughometers that measure pavement roughness in terms of inch/mile. Some agencies have already calibrated their devices to the 1/4 car International Roughness Index (IRI) while others are in the process of calibrating their devices. Hence, the present PSI equations cannot be used by most SHA. A correlation between the IRI and the PSI <u>must</u> be developed prior to the evaluation of the AASHTO equations. Such correlation will have countless benefits to all SHA as well as to their pavement management systems. Nevertheless, two preliminary statistical equations relating the PSI and the IRI have been developed and are being used by the State of Maine DOT and the State of South Carolina DOT as follows:

   State of Maine DOT equation:

   $$PSI = 9.577 - \{4.394[\log(IRI/5.9597)]\} \qquad \text{for } 5 > PSI > 0.0$$

   State of South Carolina DOT equation:

   $$PSI = 5\{\exp[-0.0286(IRI)]\}$$

   where: IRI = the International Roughness Index (in/mile);
   PSI = pavement serviceability index;

log = log to base 10; and
exp = exponential.

Although the South Carolina's equation seems to be better than the Maine's (maximum possible PSI is 5), the accuracy and sensitivity of both equations need to be examined prior to its use in this research.

The implication of the above discussion is that the AASHTO equations must be evaluated using several techniques. Each technique should be capable of providing the proper engineering interpretations of the resulting equation. The specific technique to be used will depend on the data availability. For example, the inventory data (layer thicknesses and properties) from the National Database can be used to conduct a mechanistic analysis of the various pavement sections for the purposes of calculating the stresses and strains induced in the pavement due to a wheel load and the resulting pavement surface deflections. The mechanistic analysis can be conducted using several available computer programs such as ILLI-PAVE, MICHPAVE, ILLI-SLAB, VESYS, CHEVRON and others. Statistical analysis can then be used to relate the load related distress data (e.g., rutting, faulting, fatigue cracking) in the database to the calculated stresses, strains, deflections, and layer thicknesses and properties. If such correlations can be found (Dr. Baladi has found such correlation for 200 pavement sites and developed a fatigue equation and a rut model for the MICHPAVE computer program) then the effects of the various material properties (e.g., resilient modulus) on pavement distresses can be found. Since material properties are correlated to layer coefficient in the AASHTO procedure, then the validity of such correlations can be judged and consequently calibrated. It is the opinion of the authors that mechanistic-based pavement prediction models can be found for most pavement distresses and that this technique will lead to the proper evaluation of the AASHTO equations and will optimize the benefits of the study.

Using the mechanistic evaluation procedure, another type of verification may be appropriate to determine whether specific material parameters/properties can be ignored from consideration in the pavement performance model (it possesses little to no effect on the results). The following discussion is for illustrative purposes only, insofar as reference to statistical correlations between material properties and their mechanistic responses (stresses, strains, and deflections) to load and pavement performance is concerned. Several results (again, using LTPP data and material properties) are possible including:

1. Certain material properties (e.g., resilient modulus) appear to have specific effects on pavement performance which can be related to certain identifiable patterns of those properties using the inventory data of the various pavement sections.

2. Certain material properties (e.g., Poisson's ratio) appear to have no effects on pavement performance. That is, regardless of the range of the property and its variation, the pavement performance is more or less constant for the entire range of that property.

3. Variations in the values of the pavement performance appear to have similar patterns that can be related to variations in the material properties.

The results of such evaluations will have potential impacts on this study as well as on other SHRP projects such as A-005 and A-003A. Hence, preliminary and final findings obtained by other SHRP contractors and by SHA will be consulted and the findings of this study must be communicated to them.

One additional and very important point should be addressed relative to the overall objectives of the LTPP studies. The final findings of the studies <u>must</u> address the concerns of the State Highway Agencies. Hence, they should be delivered in an implementable form without causing additional burden on the agencies. Nevertheless, the benefits of implementing the findings of this study must include:

1. Calibrated and revised AASHTO design equations based on the mechanistic response of the various pavement layers.

2. An equation for the calculation of PSI and loss of serviceability based on the IRI.

3. Modification or recommendations for modifications of the equivalent load factors (ELF) to be used in the design of pavement structures as well as in the prediction of pavement distresses.

4. Mechanistic-based pavement distress prediction models that include most load related distresses.

5. A better understanding of the factors that affect pavement design and performance.

6. A better understanding of the effects of pavement maintenance on its performance and life cycle cost.

7. Improvement to existing pavement management systems

8. Improved method for calculating the remaining life of the pavement structure and hence, improved overlay design procedure.

9. Quantified understanding of the effects of loading, environment, material properties and variability, construction quality, and maintenance levels on pavement distress and performance.

10. Development of a strategic approach for the analysis of future LTPP data that support the overall goals of SHRP and LTPP and reflect the priority needs of the State Highway Agencies through the appraisal of the potential of the data to effectively meet those needs.

11. Implementation of the analysis approach so that final products are delivered by September of 1992.

To summarize, the products of this study <u>must</u> assist the highway agencies to answer several important questions including:

1. Are the long-term load effects (load magnitude, type, frequency, and summation of loads) now correctly evaluated for pavement design and construction methods?

2. Are the Equivalent Load Factors (ELF) developed from the AASHO Road Test accurate enough to be used over a wide variety of pavement strengths, material types, environmental conditions, and the various pavement distresses?

3. What are the relative effects and interactions of load and environment (climatic) variables on pavement deterioration, performance, and service life?

4. What are the effects of varying subgrade material types and strengths on pavement construction requirements and ultimate performance?

5. What is the load-carrying capacity of a pavement when the design life is reached?

6. What are the effects of alternative drainage designs on pavement performance and service life?

7. What are the relationships between PSI and pavement roughness as measured using the IRI scale?

8. What are the effects of tire pressure on pavement performance?

9. What is the reliability of existing procedures for diagnosing the various types of distress observed in in-service pavements?

10. What is the validity and accuracy of extrapolating information from the present to future design methods to predict performance under various conditions (e.g., increased traffic loadings, higher tire pressure, new construction or maintenance practices or techniques, and new or different materials)?

11. Are the collected data adequate to evaluate the existing health of the network and to predict its future conditions?

12. What types of field data are needed for better pavement analysis and design?

13. Is it possible to efficiently and effectively improve the life of the pavement by using better design methods?

14. What types of feedback data are needed to check and, perhaps, improve existing policies and standards?

15. What are the best policies to be implemented to upgrade the pavement network conditions or at least maintain its health?

16. What are the priority settings of the various projects within a pavement network? What are the consequences of the established priorities? On what basis should this priority be established to optimize the health of the network at the given set of constraints?

17. What are the consequences of delaying or cancelling rehabilitation projects?

18. What rehabilitation alternatives are available and what are the benefits and costs of each alternative?

19. What are the proper design and construction procedures for pavement rehabilitation and overlays to provide an economical renewal of pavement life?

20. What are the effects of various types and levels of pavement maintenance on pavement life and performance? What is the cost-benefit of pavement maintenance?

21. What is the cost of differed maintenance and the ultimate effect on the life of the pavement network?

22. What are the effects of climatic and environmental variables on pavement life and pavement performance?

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EXECUTIVE SUMMARY

LTPP DATA ANAYLYSIS FOR UK ROADS

(Research sponsored by the UK Science and Engineering Research Council)

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INTRODUCTION

The LTPP study is expected to generate pavement performance data from which new or improved relationships for pavement design and management will be derived. Although most LTPP sites are located in North America, the study covers a wide range of pavements in a variety of environments including those experienced in Europe and other parts of the world. The Science and Engineering Research Council (SERC) in the United Kingdom is sponsoring collaborative research with SHRP to facilitate exchange of information during the next three years of LTPP data analysis. The primary object of the SERC research is to provide improved relationships for modeling pavement performance in the U.K. This will encompass an evaluation of existing pavement performance relationships using LTPP data as it becomes available. From this it is anticipated that modifications to existing relationships will be derived. Where possible, entirely new performance relationships will be derived if the data trend justifies such action. Of particular interest to the UK will be the LTPP studies on pavement types for which there are currently no proven performance models in the UK. These are mainly pavements with PCC layers such as in GPS-3, GPS-4, GPS-5, GPS-7 and GPS-9. The SERC research will also attempt to identify areas where data from the LTPP may not be directly applicable to the UK. An example of this are results from SPS-3 to SPS-7 which will need to be interpreted with care taking into account differences in maintenance and rehabilitation design as well as construction practices.

DATA CONVERSION

One consequence of international collaboration in the LTPP data analysis is some degree of incompatibility in data measurement standards. Pavement performance variables, both dependent (distress) and explanatory (pavement structure, traffic, environment, subgrade) will need to be harmonized so that the data measured is universally applicable. Examples of this are LTPP measurements of deflection using the falling weight deflectometer (FWD), surface distress measurements from PASCO, profile measurements, etc. In the UK, pavement deflections are still measured mainly using the Deflectograph although FWD measurents are now becoming more widespread. Pavement surface distress is measured in terms of 'Major' and 'Minor' deterioration as required for maintenance management purposes ('Minor' deterioration is defined as surface distress which requires only surface treatment). Profile measurements in the UK are largely done using the TRRL High-speed Road Monitor (HRM). Statistical correlations between FWD and Deflectograph measurements will be required. Similarly correlations are required for surface distress measurements, profile measurements and others not used in the UK. This data conversion together with the installation of the SHRP Information Management System (IMS) constitutes the first phase of the SERC contract.

GPS EX. ERIMENTAL DESIGN EFFECTIVENESS FOR UK ROADS

In order to instill confidence in the analysis of data from the LTPP, it is necessary to assess the ability of such data in representing pavement performance throughout the U.K. The concept of experimental design efficiency has been applied to study the effectiveness of GPS matrices. The same principle will be applied to estimate the effectiveness of GPS matrices for UK purposes. The vast majority of roads in the UK and throughout Europe fall within the 'Wet Freeze' and 'Wet No-Freeze' matr cells in the GPS. Consequently, the experimental design efficiency anal for the UK can be conducted using one-half of all GPS matrices. Prelimi analysis indicate an increased efficiency over that calculated for the complete GPS matrix. A preliminary conclusion is therefore that the GPS factorial matices, with pavement sections currently available for measur ment, would be more efficient in represnting the performance of the cros section of pavements found in the UK than that found throughout North America. This is perhaps an obvious fact since the range of environment encountered in North America is considerably more varied than that in th UK or Europe. The apparent increase in efficiency is due to the fact th are currently more gaps in the 'Dry' half of GPS matrices than in the 'W half. A more detailed analysis of the GPS experimental design efficienc will be conducted when the inference space for UK roads has been determi more accurately. This will be done during phase II of the SERC research

UK DATA ANALYSIS PROCEDURES

The primary objectives identified in the SERC contract for UK data anal are as follows;

1. Evaluate existing UK pavement performance relationships using data emanating from the LTPP.
2. Calibrate existing relationships where necessary in order to provide better prediction models.
3. Derive new pavement performance relationships especially for pavement constructions for which there are currently no prove models.
4. Investigate alternative models for pavement performance as mo time-series data become available.
5. Study results of the maintenance/rehabilitation effectiveness experiments.
6. Identify areas where additional data will be required for UK-specific pavements.

The first part of the UK data analysis will be to collate pavement per formance models currently used in the UK. The evaluation of these mode will essentially comprise a series of sensitivity analyses to identify explanatory variables with significant effect on pavement performance. The significance will be quantified in cost terms i.e. to study the effects of changes to significant variables on life cycle costs. The UK Whole Life Cost Model developed by the TRRL will be used to conduct the final part of the sensitivity analyses. The objective here will b to identify explanatory variables used in design equations and quanti the effects of variations and rehabilitation pavements. Variables wit high significance levels will justify higher expenditure in data colle prior to design in order to determine these variables more accurately.

UK DATA ANALYSIS PROCEDURES (CONTINUED)

Conversely, variables shown to be less sensitive in design equations need not be determined with high accuracy levels prior to design. For example if design equations for pavement rehabilitation are shown to be sensitive to changes in deflection, then higher expenditure in determining deflections more accurately is justified. Conversely, if deflections are found not to be sensitive in rehabilitation design equations, then only a few deflection measurements over length of a road section are necessary, hence reduced costs in deflection measurements.

New pavement models will also be derived in addition to calibrations to existing relationships. This however will be dictated by data availability. New relationships are required particularly for roads with PCC layers. Where data from the LTPP is felt to be insufficient for UK purposes, more test sites will be recommended. This latter analysis will form part of phase III of the SERC contract. Included in this phase will also be the study of results from the maintenance and rehabilitation effectiveness experiments in SPC-3 to SPS-7.

EXPECTED PRODUCTS FROM SERC FUNDED RESEARCH

The ultimate result of the UK data analysis research would be modifications to current UK pavement design and management specifications. This goal however, will only be achieved if all the tasks included in the three phases of the SERC research are conducted successfully. Alot will depend on the quantity and quality of the data emanating from the LTPP experiments. It has been suggested that the impact of the LTPP on pavement design, construction maintenance, rehabilitation and management will be similar to that after the AASHO Road Test over 30 years ago. If this prediction turns out to be correct, then we can expect to have new pavement design and rehabilitation manuals in the coming decades together with new methods of road maintenance management.

Dr. Henry R. Kerali
Denver, Colorado
August - 1990

Session V

THE SPECIFIC PAVEMENT STUDIES*

by

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INTRODUCTION

The Long-Term Pavement Performance (LTPP) portion of the Strategic Highway Research Program (SHRP) consists of two sets of studies: The General Pavement Studies (GPS) and the Specific Pavement Studies (SPS). The General Pavement Studies covers many objectives of the LTPP through monitoring of in-service existing pavements with varied design factors and site conditions. Test site selection for the GPS has been in process for over two years and approximately 800 test sections have been identified in the U.S. and Canada. However, existing pavements simply do not provide all the comparisions and parameters needed to study the effect of certain important factors on pavement performances. The Specific Pavement Studies have been structured to develop better understanding of the effects on performance of a few targeted factors not widely covered in the General Pavement Studies.

STUDY TOPICS

During the course of SHRP's research design, eighteen initial SPS topics were proposed. Over the last several years, SHRP's advisory groups and highway agencies selected the highest priority features. Those where improvement potential appears most significant or where current practices are most unriable. Through this process, eight experiments, designated SPS-1 through SPS-8, have emerged as top priorities. These experiments are grouped into four categories as follows:

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1. Structural Factors
   SPS-1: Strategic Study of Structural Factors for Flexible Pavements
   SPS-2: Strategic Study of Structural Factors for Rigid Pavements
2. Pavement Maintenence
   SPS-3: Preventive Maintenance Effectiveness of Flexible Pavements
   SPS-4: Preventive Maintenance Effectiveness of Rigid Pavements
3. Pavement Rehabilitation
   SPS-5: Rehabilitation of Asphalt Concrete Pavements
   SPS-6: Rehabilitation of Jointed Portland Cement Concrete Pavements
4. Environmental Effects
   SPS-8: Study of Environmental Effects in the Absence of Heavy Loads

The Specific Pavement Studies on structural factors (SPS-1 and SPS-2), pavement rehabilitation (SPS-5, SPS-6, and SPS-7), and envirnomental effects (SPS-8) are part of the LTPP program while the studies on preventive maintenance effectiveness (SPS-3 and SPS-4) are part of the Highway Operations portion of the SHRP.

EXPERIMENTAL DESIGN

To ensure practical and implemental experiments, the experimental designs for the SPS experiments were developed in cooperation with state and provincial highway agencies and the Federal Highway Administration. A detailed experiment has been developed for each study to include different levels of climate, subgrade soil, traffic, and factors pertaining to pavement type. Therefore, each SPS experiment requires a number of test sites located in the four environmental regions (wet-freeze, wet-no freeze, dry-freeze, and dry-no freeze).

Strategic Study of Structural Factors for Flexible Pavements (SPS-1)

This experiment will examine the effects of environmental region, subgrade soil (fine and coarse grained), and traffic rate (as a covariant) on pavement sections incorporating different levels of structural factors. These factors include drainage (presence or lack of it as provided by an open-graded permeable asphalt-treated drainage layer and edge drains), asphalt concrete surface thickness (4 and 7 in.), base type (dense-graded untreated aggregate, dense-graded asphalt-treated, and combination thereof), and base thickness (8 and 12 in. for undrained sections and 8, 12, and 16 in. for drained sections). This experiment, designed in a fractional factorial manner to enhance implementation practicality, includes 196 test sections located at 16 test sites.

Strategic Study of Structural Factors for Rigid Pavements (SPS-2)

This experiment will examine the effects of environmental region, subgrade soil (fine and coarse grained), and traffic rate (as a covariant) on doweled jointed plain concrete pavement sections incorporating different levels of structural factors. These factors include drainage (presence or lack of it as provided by an open-graded permeable asphalt-treated drainage layer and edge drains, concrete thickness (8 and 11 in.), base type (dense-graded untreated aggregate and lean concrete), concrete flexural strength (550 and 900 psi at 14 days), and lane width (12 and 14 ft). The experiment, designed in a fractional factorial manner to enhance implementation practicality, includes 192 test sections located at 16 test sites.

A supplementary experiment, designated SPS-2A, addresses undoweled plain concrete pavements with skewed joints. This experiment includes the same factor levels for drainage, base types, concrete thickness, and lane width covered in the main experiment, but only one level of strength (550 psi).

Another supplementary experiment, designated SPS-2B, addresses jointed reinforced concrete pavements. This experiment includes the same factor levels for drainage, concrete thickness, concrete flexural strength, and lane width covered in the main experiment, but only one level of base type (lean concrete).

Rehabilitation of Asphalt Concrete Pavements (SPS-5)

This experiment will examine the effects of environmental region, condition of existing pavement (fair and poor) and traffic rate (as a covariant) on pavement sections incorporating different methods of rehabilitation with asphalt concrete overlays. These rehabilitation methods include surface preparation (routine preventive maintenance and intensive preparation with cold milling and associated repairs), type of asphalt overlay (virgin and recycled), and overlay thickness (2 and 5 in.). The experiment includes 128 test sections located at 16 test sites.

Rehabilitation of Jointed Portland Cement Concrete Pavements (SPS-6)

This experiment will examine the effects of environmental region, type of pavement (plain and reinforced), condition of existing pavement (fair and poor) and traffic rate (as a covariant) on pavement sections incorporating different method of rehabilitation with and without asphalt concrete overlays. These rehabilitation methods include surface preparation (a limited preparation and full concrete pavement restoration) with a 4-in. thick asphalt concrete overlay or without an overlay, crack/break and seat with different asphalt concrete overlays (4 and 8 in.), and limited surface preparation with a 4-in. thick asphalt concrete overlay with sawed and sealed joints. The experiment includes 168 test sections located at 24 test sites.

Bonded Concrete Overlays of Concrete Pavements (SPS-7)

This experiment will examine the effects of environmental region, type of pavement (jointed and continuously reinforced) and condition of existing pavement and traffic (as covariants) on pavement sections incorporating different rehabilitation methods and concrete overlays. These rehabilitation methods include different surface preparation methods (cold milling plus and sand blasting and shot blasting), bonding agents (neat cement grount or none) and overlay thickness (3 and 5 in.). The experiment includes 96 test sections located at 12 test sites.

Environmental Effects in Absence of Heavy Traffic (SPS-8)

This experiment will examine the effect of environmental factors in the four environmental regions, subgrade type (frost-susceptible, expansive, fine, and coarse) on pavement sections incorporating different designs of flexible and rigid pavements and subjected to very limited traffic as measured by the Equivalent Single Axle Load accummulation. Pavement structure will include two levels of highway design. For flexible pavements, these will be 4 and 7 in. of asphalt concrete on 8 and 12 in. thick dense-graded untreated granular base, respectively. For rigid pavements, test sections will include 8 and 11 in. thick doweled jointed plain concrete pavements on 6 in. thick dense-graded granular base. The experiment is designed to include 80 test sections at 20 test sites.

STATUS AND REMARKS

The Specific Pavement Studies as planned require 104 test sites distributed in the four environmental regions. Test site selection for the SPS-5 and SPS-6 rehabilitation experiments started in 1989. Ten sites have been selected for the SPS-5 (Rehabilitation of Asphalt Concrete Pavements) experiment and seven for the SPS-6 experiment (Rehabilitation of Jointed Portland Cement Concrete Pavements). The remainder will be selected from projects scheduled for construction in 1990 and 1991 construction seasons. Also, two sites have been selected for the SPS-7 experiment (Bonded Concrete Overlays of Concrete Pavements) for construction in 1990 and the remainder will be constructed in 1991 and 1992. In addition, a few sites have been identified for the SPS-1 and SPS-2 experiments (Strategic Study of Structural Factors for Flexible and Rigid Pavements) for construction in 1990 and 1991 and the remainder will be constructed in 1992. Test site recruitment for the SPS-8 experiment (Environmental Effects in the Absence of Heavy Traffic) will start in 1990 for projects to be constructed in 1991 and 1992.

To help identify test sites, develop acceptable construction plans for tes: sections, and identify data monitoring and collection details, a series o: reports is being prepared for each experiment to address the following:

1. Experimental design
2. Nomination and evaluation of candidate projects
3. Construction guidelines and details
4. Material sampling and testing
5. Data collection
6. Monitoring activities

Although several test sites have been identified for a number of the SP: experiments, more sites are still needed to complete the experimental design an help ensure the success of the studies and the accomplishment of the LTP objectives. SHRP encourages each state and provincial highway agencies to revie the agency's construction and rehabilitation programs and recommend test site for inclusion in the SPS experiments.

ACCESSING THE DATABASE: POLICIES AND PROCEDURES

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BACKGROUND

The largest single component of the Strategic Highway Research Program (SHRP) is the Long-Term Pavement Performance (LTPP) project. This project will evaluate the performance of designated pavement sections in the United States, Canada, the United Kingdom, Australia, the Nordic Countries, and several others. The pavement sections have been specifically selected from existing roadways (General Pavement Sections or GPS) to meet criteria established for the project. Other pavement sections, labeled Special Pavement Sections (SPS) have been constructed or modified for evaluation of different designs or maintenance treatments. The LTPP project will collect data on the materials properties, environmental conditions, traffic, maintenance and rehabilitation, surface conditions and pavement responses for each of these sections.

An information management system (IMS) has been designed to store and report these data in a form that is meaningful to pavement researchers. LTPP activities will continuously monitor roadway deterioration during the 20 year experimental period, and the information management system will collect, manage and distribute the resultant data. This paper briefly describes the architecture of the information management system, then discusses the transfer of the LTPP data to pavement researchers.

THE LONG-TERM PAVEMENT PERFORMANCE INFORMATION MANAGEMENT SYSTEM (LTPP-IMS)

The 20-year lifespan of the LTPP project assures that there will be a considerable number of changes in the pavement monitoring equipment, highway section identifications, and even goals of the project. Likewise, changes will occur in computer system hardware and software. Accordingly, the IMS has been designed to be flexible, yet maintain stability in its interface with the system operators and end users of the data.

Another critical factor in system design was the realization that during the project lifetime, the monitoring of a large number of pavement sections will generate vast quantities of data. In the United States and Canada alone, there will be over 700 test sections and an additional 200-300 test sites, each of which will contain 8 or more test sections. These will be continuously monitored over the 20 year period. Selection of the appropriate computer hardware and a database management system for control of this volume of data will be crucial to system success and achievement of the LTPP project goals.

A third criterion for IMS design is the nature of the pavement data itself. These are of many types, complicated in character, and collected from multiple sources. Relationships among these data types are complex. Recognition of these facts requires a data management philosophy which transcends computer hardware and software. The IMS was designed to provide a logical interconnection of the data from which the end user may draw any desired correlations.

There are several types of pavement data:

- *Inventory Data* consist of basic pavement section identification, geometric details, materials properties, and historical maintenance and cost information.

- *Maintenance Data* are collected each time maintenance operations are performed on each pavement section.

- *Rehabilitation Data* are recorded each time rehabilitation activities are performed after initiation of section monitoring.

- *Traffic Data*, including historical (pre-monitoring) and actual traffic volume classification and axle loads, will be recorded for all sections during the experiment.

- *Materials Testing Data* are collected as a result of field sampling of all test sections. Core sampling has revealed the pavement layer structures and their components.

- *Environmental Data* for each section include weather conditions such as rainfall, temperature, solar radiation and freeze-thaw cycles.

- *Monitoring Data* are further subdivided into these categories:

    - Surface Distress
    - Transverse Profile (rutting)
    - Deflection Data, resulting from tests using Falling Weight Deflectometers
    - Longitudinal Profile

In many cases, the monitoring tests result in machine readable results. The IMS has been designed to read these results directly, filtering and cross-checking as required, and loading them into the appropriate data tables.

With a system as broadly defined and sophisticated as the LTPP-IMS, data security and backup procedures are compulsory. The IMS design, by its multi-nodal nature, provides for some controlled redundancy to protect against data loss. Backup procedures are in place to protect against accidental destruction of the files.

IMS STRUCTURE

There are five nodes in the LTPP-IMS network. A Regional IMS (RIMS) has been established at each of the four SHRP Regional Offices located in Buffalo, NY (North Atlantic RIMS); St. Paul, MN (North Central RIMS); Austin, TX (Southern RIMS); and Reno, NV (Western RIMS). The National Information Management System (NIMS) is located at the Transportation Research Board in Washington, DC. Each RIMS collects pavement data provided by the states in its region. It performs certain data validation procedures on the data, then forwards these data to the NIMS, where it is stored in a "shadow" database until it has been checked further. Data exchange between the RIMS and the NIMS is accomplished via mailing of tape cassettes rather than telecommunications, since large volumes (up to 6 megabytes) can be transferred relatively inexpensively this way. Telephone communications are more costly, and the data are not extremely time sensitive.

Raw data are continuously stored in the state and regional offices, while only data which have passed the data validation checks performed by the RIMS's and the SHRP LTPP Technical Advisory contractor (P-001) are stored in the NIMS. A summary of the kinds of data stored in the regional locations and by the central NIMS is shown here:

DATA TYPES
AND
STORAGE LOCATIONS

REGIONAL STORAGE: "RAW DATA"	NATIONAL CENTER: "PROCESSED DATA"
Distress Photographs	Material Properties
Core Samples	Historical Data
W.I.M. Data	Environmental Data
Laboratory Data Sheets	Inventory Data
Field Testing Data	Monitoring Data

Recent developments in microcomputer technology have led to selection of high-end 80386 machines as the hardware platform in the RIMS. The NIMS, which acts as the central repository for all LTPP data, requires a more powerful minicomputer platform. A Digital Equipment Corporation MicroVAX 3900 is installed at the NIMS to fulfill this requirement. The VAX is connected to a Compaq 386/25 through a high-speed Ethernet link. The Compaq matches the configurations located in the RIMS.

The IMS software is a relational database management system. Such systems have the capability of providing cross linkages among tables (or "flat files") of data, which is one of the requirements of the LTPP IMS. Different users of the IMS will want to evaluate different sets of pavement data and different relationships among them. A relational database management system extracts subsets of the data table columns for some users, creating tables of smaller aspect. The relational database approach can, conversely, join selected tables and produce larger tables for other users. The specific software chosen to perform these tasks, as well as the database housekeeping functions is ORACLE©. This product operates on both the Compac 386 and the VAX platforms, and includes the industry standard Structured Query Language (SQL) for data manipulation and database maintenance. ORACLE© also includes a form management package, report writer, and menu manager. Numerous third party products have been developed to interface with this software.

The Compac equipment uses the MS-DOS operating system, while the VAX uses the VMS operating system. A telecommunication link has been established to allow the SHRP P-001 contractor to sample the data residing in the "shadow" database on the VAX, perform an intensive series of data validation routines on that data, then either accept or reject the data. The accepted data are moved into the main NIMS database, and the rejected data are returned to the regions for further data checks. The regions may need to contact the data sources to obtain verifiable data. Only data in the main NIMS database are subsequently released to end users.

A summary of the NIMS/RIMS configuration is provided below:

LTPP-IMS HARDWARE AND SOFTWARE

	HARDWARE
PC's and Peripherals	Compaq Deskpro 386/25 Personal Computer Everex Cartridge Tape Drive Optical Disk Drive (Planned 9/90)
Minicomputer	DEC MicroVAX 3900 with 9-Track Tape Drive (National Center Only) LAN Interconnect (National Center Only)
	SOFTWARE
Database Management System	Oracle Relational Database Management System
Applications Programs	C Language

DATA AVAILABILITY POLICY

On November 21, 1989, the SHRP Pavement Performance Advisory Committee published a Data Availability Policy to describe measures to be adopted to prevent premature release of incomplete or unchecked LTPP data to the pavement research community. In recognition of the many quality assurance checks to be applied to the data before it becomes public domain, the policy provides for a staged release of the data. The policy specifies two general categories of data release:

- *Category 1* - Data from each test section will be readily available to those agencies who have collected or are processing the data for SHRP, regardless of the data condition with respect to its position in the IMS data flow process.

- *Category 2* - Data in this category may be released for general access when they have met all of the following conditions:

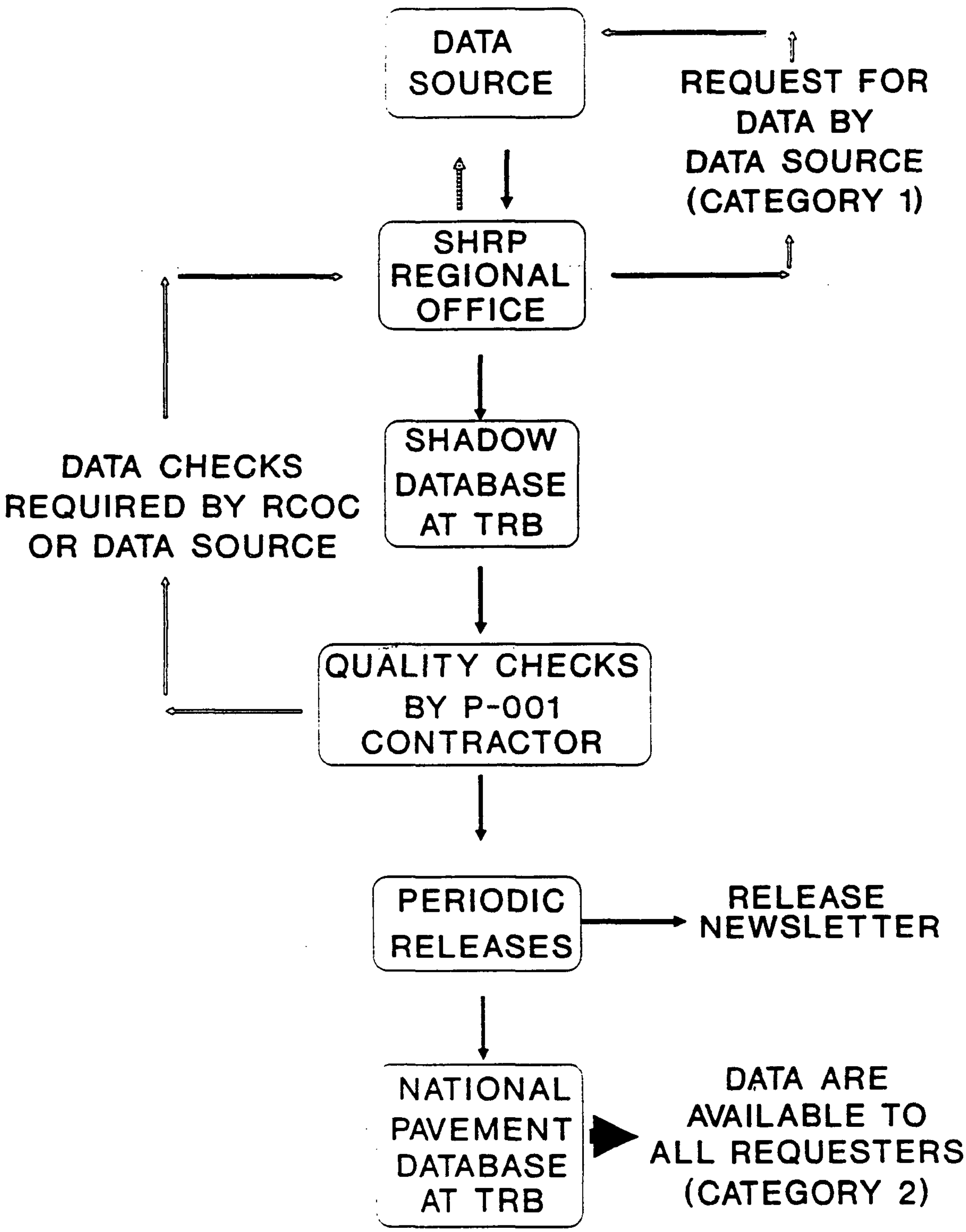
  a) All inventory data have passed:
     - quality control checks <u>and</u>
     - consistency checks of core samples with layer information <u>and</u>
     - all layer/core sample conflicts have been resolved

  b) At least one set of profile measurements have been made with summary statistics stored and passed quality checks.

  c) An estimate of cumulative traffic loads since the section was opened, or subject to major rehabilitation, has been entered into NIMS and passed quality checks.

Category 1 requests may be fulfilled by the appropriate RIMS, while all Category 2 requests must be submitted to the NIMS database manager at the Transportation Research Board in Washington. The requests may be made by telephone, by personal visit, or by correspondence.

Overview of LTPP Data Flow



Telecommunications access for Category 2 requests is not available. There are several reasons for this. As mentioned earlier, the data are not considered to be time critical, so online access is not required. Second, it is expected that responses to requests will generate more data than can be reasonably provided via telephone lines, which have low throughput capacity. Third, it is unlikely that end users could easily develop sufficient familiarity with the IMS software to construct online queries. These operations will be performed by the system operator, and the results provided to the requester in a suitable format.

FORMATS AVAILABLE

Responses to queries will be provided on magnetic media to allow end users to manipulate the data. Standard 5¼ inch 1.2 Mb and 3½ inch 1.44 Mb high density floppy diskettes will be available for use with microcomputers. Users with minicomputers or mainframes may request that their query responses be provided on 9-track 6250 bpi magnetic tape. The magnetic medium of data exchange within the RIMS/NIMS network is 60 Mb DC 600A tape cartridges, of the type normally used for backup of fixed disks on local area networks. This format will also be available to those end users who have the facilities to read such cartridges. Printed reports may also be provided, although it is anticipated that users will want these primarily as a check against the magnetic media.

The Data Availability Policy states that "a nominal servicing charge will be applied to cover the cost of media, postage and report building."

REPORTS

There are over 100 database tables in the IMS. These are of various types: administrative, lookup, data, and utility. These tables form the basis for generation of output reports, which are grouped by data categories: General, Monitoring, Inventory, or Testing.

1 General Reports

General reports are not specific to a particular module of the database. Their contents are cross-cutting across all database modules or do not pertain to any specific module.

1.1 Schema Listing Report

This report provides a listing of all table definitions in the IMS. The Tables are printed in alphabetical order. Columns within a table are printed in column number order. This report is available to end users as a guide to the system, but is primarily a maintenance tool for the system operators.

1.2 Section Totals Per State

This report lists the states of the U.S. alphabetically in the left column, then shows the number of sections assigned to each LTPP experiment for that state.

1.3 Codes Table Listing

Throughout the IMS, codes are used to control responses and reduce the keying time required for input. Coded values are listed on data collection sheets, appendices, and in LTPP manuals. To obtain an inventory of all the coded values or set of values used in the IMS, a user may request a Codes Table Listing. For each set of codes, the name of the table, a description of the content, and the source of the information is provided. An excerpt of a Codes Table Listing is shown here:

SHRP LTPP IMS
CODES TABLE LISTING

CODE NAME: ASPHALT
DESCRIPTION: Grades of Asphalt, Emulsified Asphalt, and Cutback Asphalt Codes
SOURCE: Table A.16 from the DCG

Code	Description
1	Asphalt Cements AC-2.5
2	Asphalt Cements AC-5
3	Asphalt Cements AC-10
4	Asphalt Cements AC-20
5	Asphalt Cements AC-30
6	Asphalt Cements AC-40

...ETC.

1.4 Sections by State

A report ordered by state, experiment type, then SHRP section number may be requested for a specific state, group of states, or all states. For each state chosen, the report lists all the SHRP sections, defined by route, number of lanes, direction of travel, milepoint, and county.

1.5 Pavement Summary

The Pavement Summary report provides a history of the pavement structure for a specified section. The summary of the inventory (i.e., pre-monitoring) layer information is presented, followed by a summary of the layer structure stored in the reference table for each construction event which occurred during monitoring of the section.

1.6 Section Reference

The Section Reference report displays, by state and section number, general section identification information, such as SHRP and state identification numbers, district, county, functional highway class, highway number, mile marker, number of lanes, type of pavement, and location information.

2 Monitoring Reports

Monitoring reports display results of LTPP monitoring activities as they were entered into the IMS.

2.1 Skid Measurement

For specified states or section numbers, the Skid Measurement report displays skid test results by skid time, length of skid, speed of vehicle, method used, and other criteria.

2.2 FWD Deflection Test Results

This report displays the results of Falling Weight Deflectometer tests for specified pavement sections. Included are the mean of all drops at a given height in a specified lane, the standard deviation of all drops at a given height in a given lane, and peak data. An abbreviated excerpt of a FWD Deflection Test Results report appears below:

26-JUN-90

SHRP LTPP IMS
FWD DEFLECTION TEST RESULTS SUMMARY

SHRP Section ID: 241632 Unit ID: 8002-058 Test Date: 19-APR-89
Test No 100036
Temp Units: F Station Units: Feet Load Units: psi Deflection Units: mils
# of Active Deflectors: 7
Plate Radius: 150 Load Cell Serial No: 110
Load Cell Relative Gain: 1.014
Load Cell Initial Gain: 92
Mean of all drops at a given height in a given lane
Measured Deflection by Sensor

Lane	Hght	Load	1	2	3	4	5	6	7	DTE	Pvmt Temp	Air Temp
F1	1	52.24	4.38	3.82	3.54	3.11	2.72	2.06	1.18	0.00	53.6	57.7
	2	80.51	6.81	5.98	5.54	4.89	4.26	3.23	1.87	0.00	53.6	57.7
	3	109.76	9.50	8.28	7.67	6.76	5.89	4.46	2.59	0.00	53.6	57.7

2.3 Profilometer Summary/Graph

This report provides the results of the profilometer tests for a state, section number, and profilometer test date. The results are provided in both tabular and bar graph format.

2.4 Distress Summary Report

For a specific pavement type, state(s) and section number(s), the Distress Summary Report provides distress summaries for the test section(s).

2.5 PASCO Rut Results

This report displays general information about the pavement cross profile and rut depth data for specified sections.

3 <u>Inventory Reports</u>

Inventory Reports provide descriptive data collected on each pavement section as it was initially entered into the IMS.

3.1 Detailed Listing

The Detailed Listing report provides documentation of IMS inventory data for a specific SHRP pavement section. These data may be useful for data verification, documentation for a permanent file or distribution to states and regional data collection contractors as a description of the section. Because of the exhaustive nature of this report, it appears as several data sheets.

3.2 Cross Check Report

The Cross Check Report is used by system operators as a data validation tool. The report provides checks to determine if data for a system field are consistent with data entered for other fields. If inconsistencies are found, the cross check report is automatically generated, indicating the fields that are inconsistent.

4 Maintenance Reports

Maintenance Reports provide histories of pavement section maintenance or rehabilitation actions and costs.

4.1 Maintenance Summary

The Maintenance Summary report shows the maintenance history of a pavement section. This report provides information on treatments for pavement cracking, rutting, weathering, and other distress conditions.

4.2 Cost/History Report

This report provides a complete history of maintenance activities and a breakdown of maintenance costs for pavement sections. Both total cost and average cost/unit are provided for materials.

5 Testing Reports

Testing reports describe field tests and their results as well as laboratory protocols used and the results obtained in SHRP contractor laboratories. A special report reproduces laboratory sheets designated as L05, L06, and L07, as described below.

5.1 Field Testing Report

The Field Testing report provides a listing of all the core sample and borehole information obtained for a specified pavement section. Further information is provided on core holes, test pits, and probe results. These data are listed by strata level.

5.2 Laboratory Testing Report

This report provides a listing of all laboratory data obtained for a specified section. The data are provided by protocol, then alphabetically by test type.

5.3 L05 (Reference Layer), L06, and L07 Testing Report

The testing laboratories fill out several summary level forms indicating the pavement structures and the disposition of the samples. Laboratory forms L05, L06, and L07 are the only summary forms stored in the IMS.

DATA EXTRACTION

In addition to generation of these reports, the NIMS and RIMS system operators have the option of selecting subsets of data from the IMS database. The system query structure allows entry of queries by specified pavement section(s), for all sections in a state or region, or for a specified experiment type. Further selection by data module (i.e., Inventory, Rehabilitation, etc.) and categories of data within the modules allows for specificity of responses from the system.

To begin the data extraction process, the system operator selects from the Data Extraction Menu shown below:

```
                    DATA EXTRACTION MENU                    Ver. 2.0
--------------------------------------------------------------------

              1.    By Section

              2.    By State

              3.    By Experiment Type

              4.    By Region


                      Enter Menu Choice:
```

Suppose, for example, the operator wants to extract inventory data for a specified section. The operator would choose "1." from this menu for data by Section. He would then be provided with a "Selection Criteria" menu shown on the following page. Here the operator enters the two digit state code (identical to the two digit U.S. postal state code) and the SHRP section identification number for the section in question. At the bottom of the menu, the operator is prompted for a file name and a path statement for storage of the retrieved information on magnetic media.

When these steps have been accomplished the computer will display the Data Group Selection menu. This menu allows the operator to mark one or more modules from which he wishes to receive section information and have it directed to the file name which he has specified. In the example, the operator only wishes to retrieve Inventory Information, so he marks the Inventory Data line on this menu. However, he may choose Environmental Data, Laboratory Materials/Testing, Maintenance Data, Rehabilitation Data, and/or Traffic Data as well as Inventory Data, if he chooses to do so.

DATA EXTRACTION BY SECTION

Selection Criteria

State Code: __

SHRP ID: ____

Specification of data extraction results:

Path: ______________________________

File: __________

The Data Group Selection Menu appears below:

DATA GROUP SELECTION Ver. 2.0

__ Environmental Data
__ Inventory Data
__ Laboratory Materials/Testing
__ Maintenance Data
__ Rehabilitation Data
__ Traffic Data

Press <NEXT FIELD> to mark/unmark the Data Group(s) from which you want to extract data. Press <EXIT> to return to the previous menu.

Should unapproved records be included (Y/N)
Are the Data Group(s) marked correctly? (Y/N)

After all the data groups have been marked, the system prompts the operator to determine if unapproved records should be included. Answering "Y" allows inclusion of records which have not been screened for validity. In every case where the data are to be released outside the NIMS, the response to this question will be "N", but "Y" may be selected for Category 1 requests of the RIMS.

If the operator responds positively to "Are the Data Group(s) marked correctly?", the system will present a screen for data selection by the selected category. In the example, the operator has selected Inventory as the data category, and so is presented with the Inventory Data Selection menu:

INVENTORY DATA SELECTION Ver. 2.0

Ext.	Database Table	Ext.	Database Table
00	Section Identification	I12	Aggregate Durability
I01	General Information	I13	Gradation of Aggregates
I02	Shoulder Information	I14	PMA Aggregate Properties
I03	Layer Information	I15	PMA Asphalt Properties
I04	Pavement Age	I16	Modifier Information
I05	Major Improvements	I17	PMA Original Mixture
I06	PCC Joints	I18	PMA Construction Data
I07	PCC Reinforcing Steel	I19	PMA Construction/Roller Data
I08	PCC Mixture	I20	PMA Construction/Compaction
I09	PCC Strength	I21	Unbound/Stabilized/Subbase
I10	Admixture Amounts/Types	I22	Stabilizing Agent Data
I11	Aggregate Composition	I23	Subgrade Data

Press <NEXT FLD> to mark/unmark the Data File(s) from which data is extracted

Are the Data File(s) marked correctly? (Y/N)

After the appropriate selections are made from this menu, the data will be extracted and loaded into the file named by the operator. This file may be copied onto magnetic media for delivery to a requester or it may be printed for review.

CONCLUSION

The LTPP-IMS is a powerful new tool for use by domestic and international pavement researchers. The first release of data from the NIMS is expected in early 1991. As the experiment progresses, the ability to correlate large volumes of data will provide researchers with unprecedented capability to determine causes of pavement deterioration and plan for more cost-effective alternatives to present-day paving methods.

IMPACTS ON THE AASHTO GUIDE FOR DESIGN OF PAVEMENT STRUCTURES

by

William O. Hadley

INTRODUCTION

This paper addresses the potential impacts that the results from SHRP-LTPP may have on the 1986 AASHTO Guide for the Design of Pavement Structures and outlines specific topical areas of the guide which might undergo change as a result of the SHRP-LTPP program. Particular attention was given to changes expected in the guide as a result of the GPS studies since this type of information would be useful to the SHRP Data Analysis Contractors.

The potential impacts are considered on two levels. The first level represents those potential impact items with higher expectation of delivery as a result of ongoing data gathering and analysis and the SHRP Data Analysis Contracts. The second level of potential impacts are considered as those that would be generated by the results of the SPS studies, as well as, those made possible because of the expansion of the data analysis inference space to include a wide range of environmental and soil conditions.

The timing of the anticipated implementation of the research products is assigned to Short Term (available by 1992), Mid Term (available by 1997) and Long Term (available by 2002+) categories. The expected implementation time frames for the potential impact Levels I and II and possible enhancements to the various areas of the guide are outlined in Tables 1, 2, and 3 respectively.

POTENTIAL IMPACTS

The areas of the guide that could be potentially impacted by SHRP-LTPP (Table 1) include the design equations, PSI measurement, materials characterization, and variability.

The impact on the design equations would be evolutionary in nature and probably extend over the three designated timing categories. In the short term the existing equations could be improved based upon the LTPP GPS database. ... be complemented by an array of predictive equations for various distresses (i.e cracking, rutting, etc.) and a serviceability equation based on roughness (i.e PSI = f [Roughness]). The impact in the mid to long term time categories woul more than likely result from the development of a more comprehensive design procedure which encompasses consideration of a wide variety of distress types that influence decisions to undertake major pavement maintenance or rehabilitation activities. The damage equations resulting from this effort coul be similar to the present form (i.e. serviceability with ρ and β functions) or could very well assume an entirely different configuration. In any case any revisions to the equational form would be dictated by the information available in the data base and the type of analysis undertaken.

<u>PSI measurements</u> - It is believed that a simplified, more economical metho of measurement and evaluation will evolve. The analytical approach would b simplified in the sense that a present two format component format includin roughness and distress would be changed to a form encompassing pavement roughnes measurements only. The measurement methods would be simplified since manua distress surveys could be minimized or eliminated, while the roughness could b quantified by a profilometer.

<u>Materials Characterization</u> - This section of the guide will be impacte by the extensive testing program undertaken in SHRP-LTPP which will result i a comprehensive materials database, new and improved methods of materia testing, more reliable test procedures, and better guidance on material proper data entries.

<u>Variability (Materials and Construction)</u> - A better understanding of t extent and consistency of materials and construction variability will be gai from the extensive drilling, sampling and testing program. Better definit of the components of variance associated with materials, traffic and possib construction is expected. The reliability concept should be enhanced with t variability information generated in SHRP-LTPP.

The areas of the guide that could be potentially impacted at the sec level (i.e. Level II) are presented in Table 2 and include rehabilitation maintenance considerations, effective soil properties, traffic, and environme effects. Comments concerning the implication of these areas in impacting the guide are also offered in Table 2.

The projected timing to the implementation of these potential Level I and II impacts are included in Tables 1 and 2 respectively, and range from short to long term.

POSSIBLE ENHANCEMENTS

The areas of the AASHTO guide which could possibly be enhanced if additional research efforts are undertaken utilizing the SHRP-LTPP database are listed in Table 3 and include:

- initial Present Serviceability Index represented as a function of pavement characteristics, pavement type, construction type and quality control;
- improved criteria for terminal serviceability and severity of distress by highway class;
- replacement of layer coefficients with moduli/strength measures of structural layers for use in empirical-mechanistic designs;
- assimilation of type, extent and severity of distress into component indices or an overall condition index;
- a method of measuring structural capacity, joint efficiency and loss of support of PCC pavements using SHRP-LTPP FWD results;
- a better understanding of the relative effects of the contributions of load and environment on pavement serviceability deterioration resulting in expected improvements in cost allocation.

The areas reported in Table 3 are not expected to be directly impacted by the SHRP-LTPP study, work by the SHRP P-001 contractor (i.e. TRDF) or the analyses to be undertaken by the Data Analysis Contractors (i.e. P020 contractors); therefore the analytical and developmental work must be undertaken by other research agencies or entities for the enhancements to come to fruition.

TABLE 1. POTENTIAL IMPACTS ON AASHTO GUIDE OF SHRP-LTPP, LEVEL I

Item in AASHTO Pavement Design Guide	Potential Engineering Impact due to SHRP	Timing of Effect		
		Short Term 1992	Mid Term 1997	Long Term 2002
Design Equations for flexible and rigid pavements	AASHTO equation calibration; distress predictive equations	X		
	Improved design equations		X	X
	Comprehensive design procedure			X
Present Serviceability Index	Simplified, more economical, method of measurement and evaluation	X	X	
Materials Characterization	New methods & more reliable procedures; better guidance for input data	X	X	
Variances for materials & construction	Better understanding and definition; greater reliability of design	X	X	
Reliability	Upgraded reliability concepts which provide better predictions		X	X

TABLE 2. POTENTIAL IMPACTS ON AASHTO GUIDE OF SHRP-LTPP, LEVEL II

Item in AASHTO Pavement Design Guide	Potential Engineering Impact due to SHRP	Timing of Effect		
		Short Term 1992	Mid Term 1997	Long Term 2002
Rehabilitation and Maintenance	Maintenance/Rehabilitation Design Matrix based on condition, safety, & need	X		
Effective Soil Modulus	More representative resilient modulus; seasonal effect on pavement layers		X	X
Effective subgrade reaction and loss of support	Better understanding of variation; more effective use of subbase materials		X	X
Traffic	Nationwide uniformity in assessment; better understanding of characteristics	X	X	
Environmental Effects	More realistic life-cycle evaluations		X	X

TABLE 3. POSSIBLE ENHANCEMENTS OF AASHTO GUIDES
BY SHRP-LTPP

Item in AASHTO Pavement Design Guide	Possible Enhancement due to SHRP	Timing of Effect		
		Short Term 1992	Mid Term 1997	Long Term 2002
Initial Serviceability Index	Represented as a function of pavement characteristics, quality control, etc.		X	X
Terminal Serviceability	Improved Criteria		X	
Layer Coefficients	Rational moduli/strength measures and mechanistic design	X	X	
Condition Survey	Assimilation of type, severity, and extent of distress in a condition index	X	X	
NDT Analysis	Better means of measuring structural capacity, joint efficiency and loss of support		X	
Contributions of load and environmental serviceability deterioration	Better understanding of relative effects, Improved cost allocation		X	X

Long-Term Opportunities in LTPP

Lynne H. Irwin
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INTRODUCTION

Ever since the day, several months ago, that Neil Hawks asked me to offer my thoughts on "long-term opportunities" I have felt some sense of responsibility that I should try to represent the collective thinking of people other than just myself in this presentation. If I do this, I think it is inevitable that I will have to make my interpretation of your thoughts. Over the course of the last four months, either formally or sometimes informally, I have been gathering information for this talk. In addition, I have been listening very carefully over the past several days of this meeting. This report will represent my synthesis of all of these sources.

We have heard about the details of "residual analysis", the vagaries of Bayesian analysis, and had the occasional speaker flash slides past us so fast I presumed they were trying to illustrate the length of a millisecond. We heard a hundred people reiterate the objectives of LTPP (after saying that they wouldn't repeat them). And we have added a few new words to our vocabulary.

Through it all we have managed to maintain some semblance of a sense of humor, and we did not get too contentious.

I'll get to the long-term opportunities quickly, but first, just to prove that I have been listening, let me recite some quotable quotes which have come forth in the past couple of days. I feel they help us to infer the future research opportunities and needs. Let me point out that I had to write fast, and I had to paraphrase, so please correct me if I have misquoted you.

SOME QUOTABLE QUOTES FROM THIS MEETING

"We must have instrumentation in the pavements, particularly in SPS-1 and SPS-2." (Joe Mahoney)

"Recycled mixes were purposely excluded from GPS." (Gary Elkins)

"There's a need to investigate the effects of environment on pavement materials properties. This should be different than the approach used in the SPS-8 environmental studies." (Matt Witczak)

"There is a need to objectively evaluate the AASHTO pavement design/performance concepts, to determine if they are applicable, realistic, and consistent." (Marshall Thompson)
"There is a need to place more emphasis on development of the mechanistic-empirical design method." (Marshall Thompson - and many others)

"If we don't find more sites to fill in the cells for GPS-6, 7, 8, and 9, we will not be able develop rehabilitation models." (Mike Darter)

"It is going to be several years before we have the data in hand to develop the models." (Brent Rahut)

"It will be several years before the laboratory resilient moduli will be available to support mechanistic analysis of the GPS data." (Paul Benson)

"We need to begin to put summary information from LTPP in the hands of the States by no later than the end of this year if I am going to be able to cover my (hind end) and yours." (Charlie Dougan)

"Unify the data. Data sources should not matter - what is important is that the models are valid." (Michael Markow)

"Keep the data sets separate." (Chuck Marek)

"The functional form of new models must satisfy engineering principles or hypotheses regarding behavior." (Michael Markow)

"Perhaps someday we can get away from load equivalency factors." (Joe Mahoney)

"Ultimately a more fundamental measure of traffic loading should be sought to replace the AASHTO equivalent single axle load concept." (Michael Markow)

"We may have pushed the AASHTO empirical approach to the limit. We cannot simply add more bells and whistles." (Paul Teng)

"We need to incorporate what we already know into the model development process." (Jim Brown)

"Bayesian analysis methods afford an opportunity to incorporate <u>a priori</u> knowledge with small sets of data, to arrive at deterministic or probabilistic knowledge." (Dale Nesbitt)

"Bayesian analysis is something like a religion - some embrace it, others do not." (Lyle Calvin)

"What's the chances for getting additional funding for LTPP into the new Highway Bill?" (Bill MacCreery to Dean Carlson)

(SMILE) (Dean Carlson to Bill MacCreery)
"It's all a matter of priorities. Anything you want to add into LTPP, we've got to leave something else out." (Neil Hawks)

"Technology transfer cannot be arranged from the top down. It must involve user participation." (Damian Kulash)

"Give us something we can use!" (several State DOT engineers)

FROM THE CLOUDY CRYSTAL BALL

Let's see what we can glean from the above quotes, in terms of the long-term opportunities. Perhaps we can see what the crystal ball might suggest.

First, there are certain "timeless" opportunities. For instance, someday it may come to our attention that we need to measure an aggregate gradation, get an asphalt content, or whatever. These parameters are more or less unchanging over a period of years. We can measure them later, when the need and/or the realization of the need arises.

I think it is important to note that there are some data needs that we may realize in the future, but which we have not yet recognized. Certain kinds of data will still be there and available for us to get.

On the other hand, there are some "limited" opportunities. As an example, you may want to relate in situ moisture content to the pavement deflection. Both the deflection and the moisture content change over time. They won't be the same from one week to the next. As another example, frost depth beneath a pavement won't be the same from one day to the next. These are top priority items that we need to identify now and collect the data as we are doing the research.

Finally, there is a category that we could identify as "long-term" opportunities. These may someday become part of the LTPP research agenda in response to:

* changes in our understanding of the science of pavement engineering.

* improvements in equipment and instrumentation

* changing priorities and/or availability of funds

It is this latter category that I am mainly going to address myself to today, but there is some interaction between the more ephemeral kinds of opportunities and the long-term opportunities. I will cite two examples to help illustrate what I mean.

Figure 1 is an example of some deflection data taken at two specific project sites, one with a thinner pavement than the other. Both are flexible pavements with granular bases. The data were taken over a period of several years time. As you can note, the response of the stronger of the two pavements tracks that of the weaker one fairly closely, but with smaller deflections. The data comes from a northern climate, near Ithaca, New York where I live, and the effects of annual freezing and thawing are apparent.

Several things are interesting in this figure. In the first year we made eighteen deflection tests, mainly concentrated in the spring. It appeared that we could see the seasonal changes quite adequately. In the following year we were able to increase the number of tests to 27. Because of the added data, it occurred to me that there was some noise on these curves that we were only beginning to pick up. In the next year we increased to 36 tests, and we were quite able to see the noise. These are FWD deflections normalized to a 9000 pound plate load. The effect of some days being sunny and others being cloudy is more evident in the third year of data collection. However, there is also the danger that we could over-research the subject, and then we would be unable to discern the general trends. This makes modeling difficult.

Another thing that is visible in the figure is the fact that all years are not created equally. The winter of 1983 was very brief in duration, while the following winter lasted much longer. And thaw came early again in 1985. This has some serious implications to our LTPP research concepts, especially if we are going out to get seasonal variation data in different locations in different years. We may or may not be able to catch the deflections on the weakest day of the year. The weak period lasts such a short time we probably will miss it in most locations. If the models we are building require that we know the weakest deflections, this will b hard to achieve.

For a second example I provide Figure 2. It shows the typical apparatus for conducting a repeated-load triaxial test. At the GP sites we are digging test pits, and working very hard to obtain representative material for the triaxial test specimen. In the la we will make every effort to compact the specimen at the field density and moisture content. Then we will place it in a rubber membrane and place the specimen in the test cell. We will apply the cell pressure as illustrated in Figure 3, and we will isotropically consolidate the specimen. Thereafter we will apply cyclic deviator stress, and measure the strain response, and calculate the resilient modulus of elasticity of the material. This will dutifully be entered into the data base.

All of this procedure is in accordance with the SHRP protocol. However, in Figure 4 we can see that the granular material in situ at the GPS site is anisotropically consolidated. The vertical and horizontal confining pressures are not equal. If the consolidation conditions did not matter, then the SHRP test procedure would be fine. But pavement engineers are just beginning to realize that the confining conditions do matter. The resilient modulus of the granular material is very much dependent on the initial ratio of the horizontal to vertical confining stress.

These two examples serve to illustrate the fact that changes in our understanding of the science of pavement engineering can open up new opportunities in the LTPP research agenda. New research protocols may be developed, new equipment for the lab and the field may be developed, and new research objectives may ensue, due to these new understandings. However, while these are long-term research opportunities, we may someday find that there was some data that had to have been obtained at the site when the materials were sampled, in order to implement the new, improved test procedures. Thus there is some chance that the long-term opportunities may be frustrated by our inability to get everything that is needed in the current time frame.

SOME SPECIFIC LONG-TERM OPPORTUNITIES

Seasonal Variability Studies

Let's get back to the long-term opportunities. Many of the quotable quotes alluded to the fact that we need to begin to capture information regarding seasonal variability in materials properties so that we can incorporate it into pavement design and evaluation procedures. Perhaps this could be translated into seasonal variability in pavement strength. Then there is seasonal variation in pavement roughness, and in skid resistance. And there are different degrees of performance loss that take place at different times of the year.

Many pavement engineers in northern climates believe that most of the annual fatigue life consumed, and most of the performance loss that takes place, occur in a relatively small portion of the spring of the year. There is seasonality in the sun belt, too, but it is less dramatic. It is occasioned by changes in surface temperature and subsurface moisture, just like the situation in the North.

Spatial Variability Studies

As Dave Newcomb ably illustrated in his presentation, there is also spatial variability in pavement strength. Subgrade moisture content and gradation are not constant over distance. Pavement engineers are just beginning to learn that moisture content is the single largest determinant of the K_1 parameter in our resilient modulus models. Thus, to the extent that moisture content is not constant from point to point, there will be differences in the subgrade and base course modulus. We can treat this as "noise", as we are doing currently, or we can try to understand and model these phenomena through research.

In addition, construction variability is another source of spatial variability. Variations in materials and compaction also lead to spatial differences in moduli. If we do not understand the effects of moisture, density, and gradation, among others, we will not be able to separate them, and there is a danger that we will attribute all of the point to point variability to "construction variability" when it is not all the contractor's doing.

There are also microclimates as you go down a highway. Sunny and shady areas, northern and southern exposures, all affect the frost penetration, the subsurface moisture and perhaps other things that are associated with spatial variability, and all of these are long-term opportunities for us to begin to factor into our pavement research.

Better Tools Needed

We have heard many calls in the last couple of days for better tools: better laboratory equipment, better testing protocols, more well-refined procedures and devices for us to use. Think about the existence of the MTS type of closed-loop, servo-hydraulic equipment that is available today. What could we have done with that type of equipment if it had been available 30 years ago when the AASHO Road Test was conducted? Opportunities come along over time, and we should not presume that over the 20 years or so of the LTPP project our laboratory equipment and procedures and field equipment and procedures will be unchanging.

With all due apologies to the folks at Dynatest, I ask the radical question, "Will there be life after the falling weight deflectometer?" The device has not always been here, and I predict that, like the Benkelman beam, the day will come when something else has replaced it. There will be new things to measure, and new ways to measure them will be discovered as the LTPP research evolves.

We need to have a framework and some process under which we can incorporate that new knowledge. We must not become locked into a single research plan for twenty years, eighteen of which are still to come.

<u>Better Analytical Methods</u>

Many, many of you have begun asking for better analytical methods. Is there a replacement for elastic layer theory? You have talked about mechanistic and mechanistic-empirical analysis methods. The term "mechanistic" does not necessarily mean that elastic layer theory must be used as the principal method for doing fatigue failure predictions for pavements. There are other ways that we could get the stresses and strains in the surface and subsurface layers.

Several people have pointed out that we need more effective theories for predicting rutting, to enable us to better predict subgrade shear deformation and asphalt concrete wheelpath rutting problems.

There have been a number of calls to move away from the ESAL (equivalent single axle load) concept. To some extent ESAL factors resulted from the need to consolidate the large quantity of data that came from the AASHO Road Test for vehicles of different axle loadings. However, for almost twenty years in the Portland Cement Association method of pavement design it has been possible to handle mixed traffic, involving a variety of axle loads. In the AASHTO pavement design method we still choose to combine traffic into one "lumped" parameter, the ESAL factor. This is an outgrowth of slide rule technology. Today, with computers, we can deal with models that are more fundamentally correct. We no longer have to work with lumped parameters and lose the ability to distinguish the effects of vehicle-roadway interactions. Through research we will probably find that so-called ESAL "constants" are not really constant, but they vary with changing materials moduli, etc. Since materials properties vary over time, it is likely that ESAL factors are also seasonally variable.

We also have the opportunity to look for ways to incorporate probabilistic methods into pavement design. Today we use deterministic equations, where you put in the numbers, turn the crank, and come up with an answer. An alternative approach would allow the use of stochastic data, considering variability over time and space, due to construction, etc., to design in terms of the degree of confidence that is desired. Pavement engineers have not yet come to realize all that is possible in this approach.

Broaden the Research Objectives

I am keeping in mind Neil Hawk's admonishment that if we are to add anything into the LTPP research agenda, we must identify something to leave out. But I am also thinking about Dean Carlson's smile. Thus I will suggest at this point that we should consider broadening the research objectives.

The fact that we are not including any recycled materials in the study could, I think, come back to haunt us in the future. That is unless we can show that the performance of recycled materials is not substantially different than virgin materials.

There is a great deal of research going on in other areas of SHRP regarding improved and modified asphalt. Sooner or later pavement engineers are going to begin to call for field verification of the amount of improvement to performance that modified asphalt can provide.

There are a number of different pavement reinforcement methods that are available to us, which could be studied as a part of the LTPP research. These projects could become SPS-13, 14 and 15. And of course we can expand the number of ways in which we study the influence of drainage. It is said that the three most important aspects of pavement performance are drainage, drainage, and drainage.

While we are broadening the research agenda, we could also seek to improve both the quantity and quality of traffic data that will be collected for SPS. Many of you have spoken for that. There is interest in expanding our knowledge about truck-roadway interactions - how truck dynamics affect stresses and strains in the pavement.

Then there is the opportunity to study the relationships between road user costs, pavement distress, and performance. One of the missing aspects of our ability to analyze life-cycle costs is to quantify the effects of performing various rehabilitation and maintenance measures. What if we do a better job of patching potholes or overlaying the road? What does that do to the road user cost? It is important for us to keep in mind that construction and maintenance costs represent only five percent of the total life-cycle cost of a road. Road user costs represent the other 95 percent. So when we do our research on pavement science and pavement engineering, we are mainly looking at the five percent end of the issue. Potentially there are tremendous cost benefits of our research for the road user. We need to know more about those benefits, if for no other reason than to be able to explain and defend our work.

Finally, there is the opportunity to reorganize LTPP to support the development of mechanistic design methods. The future of pavement engineering lies in our ability to understand and properly use mechanistic design. I think many of us would feel more comfortable, however, if I add that we should first satisfy the objective of verifying the AASHTO design models, and perhaps extend them.

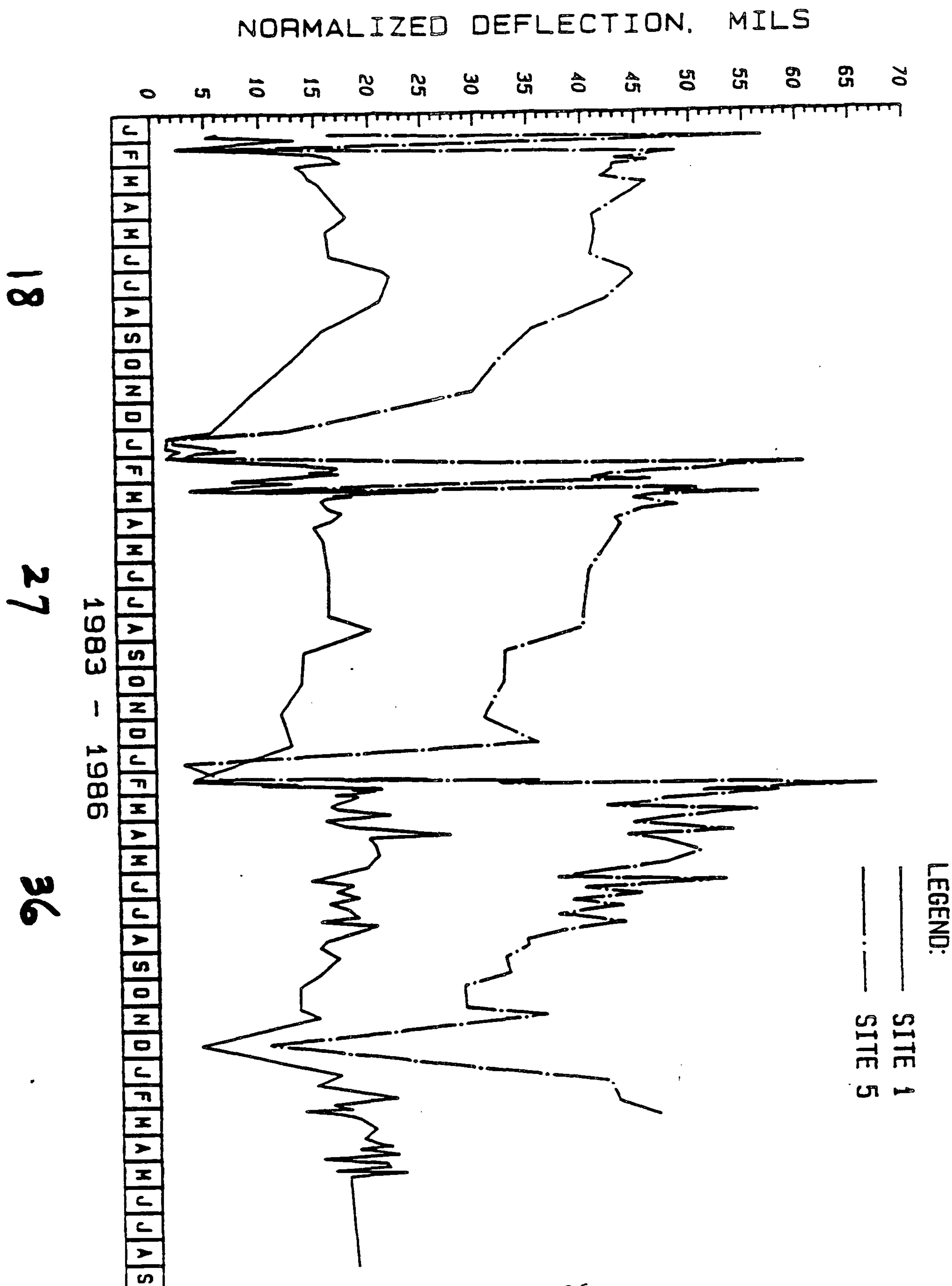
FOCUS ON APPLICABILITY

Throughout this meeting, and throughout my data gathering effort, there has been frequent mention of the need to focus on the applicability of what we do. Without question we need to conduct our pavement research to better understand the science. Almost everyone here has some frustration with our lack of understanding of the science of pavement engineering at this time. But we also need to simplify wherever possible. There will be certain factors that we research the daylights out of, which we will find are negative factors, they don't really matter, or they don't matter as much as we thought they would.

We need to keep our eye on the doughnut, so to speak. We need to understand what is important and then throw out of our tool box those things that we find are not important. There is no advantage in making pavement engineering any more complex than it has to be.

A major opportunity for LTPP in the long-term is to provide a pro-active program of technology transfer. This is one of the major elements that still needs attention in the program. We need to do more things like we are doing here: workshops, training courses, and publications. You may notice, I put publications third. That was rather radical for a publish-or-perish college professor, but it was not by accident. There is a need for person to person communication, and for user involvement in technology transfer. The <u>ways</u> in which we do it are as important as doing it.

Two days ago Damian Kulash mentioned that there were 973 days to go for SHRP to carry out its mission. Now there are only 971 left. Most of what I have been presenting as opportunities may not in fact get underway until after the end of the initial five year program. But in the interim, between now and the five-year point, and even over the remaining fifteen years that will follow thereafter, it is important that we make every decision count. As we decide what we want to put in, and hence what we must leave out, we should be very careful that real value is added, and that it is not just moved from one person's priorities to another's. That is probably the most compelling long-term need in the LTPP research program.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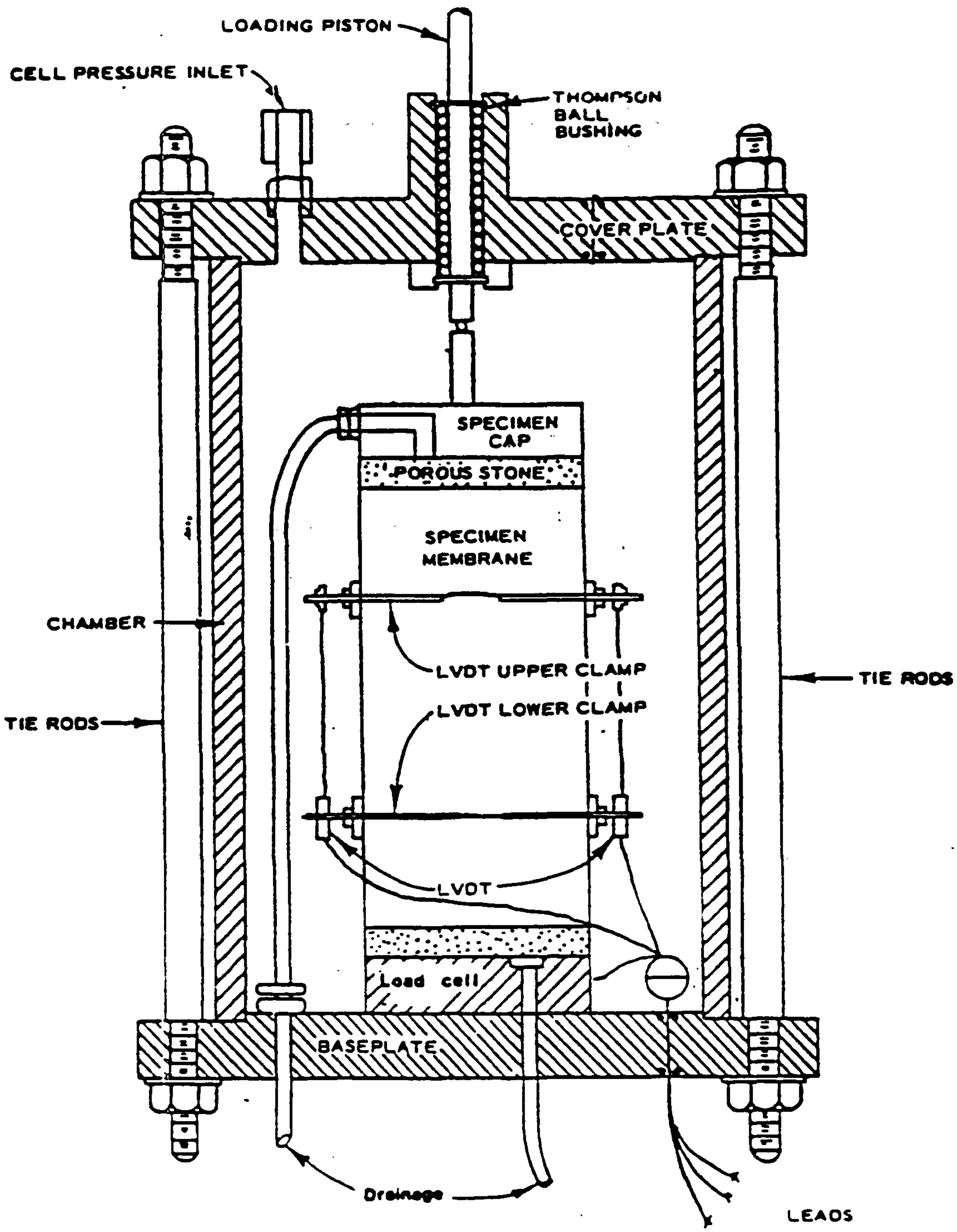

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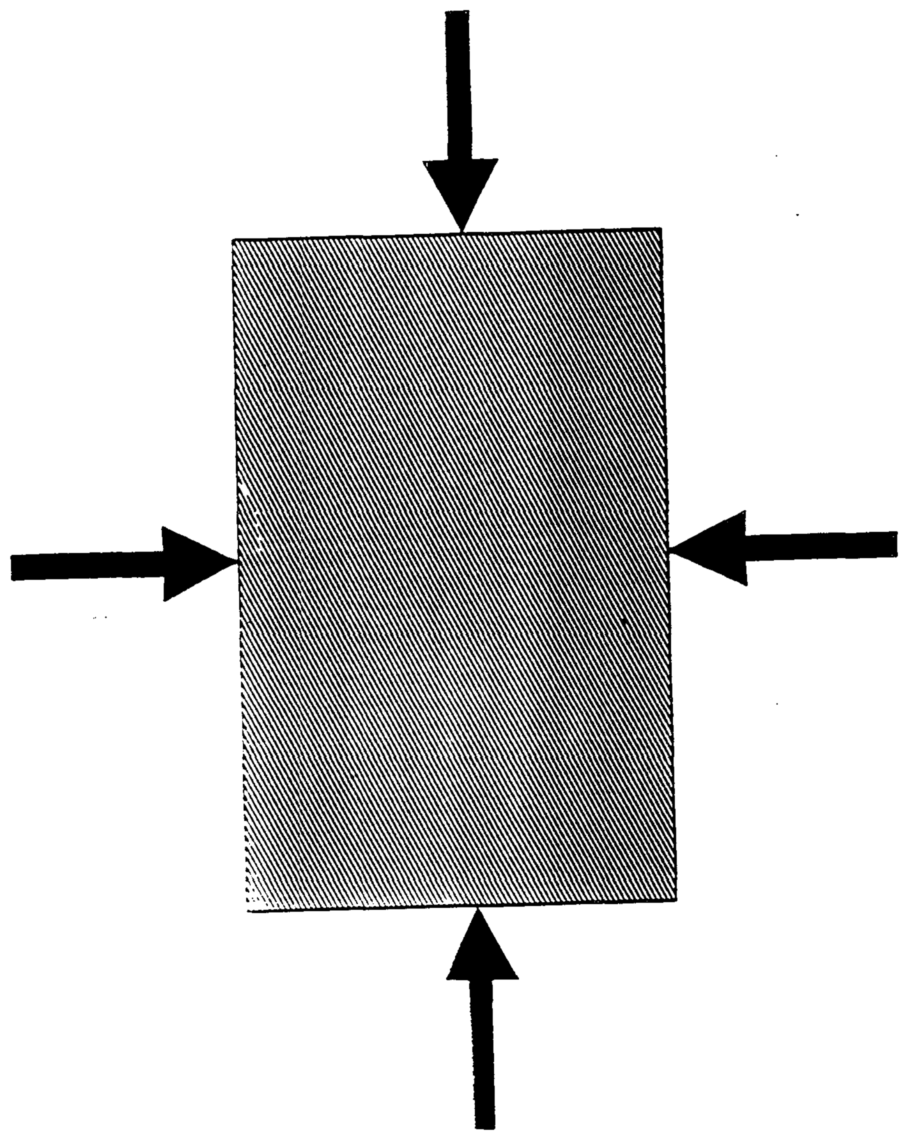

ANISOTROPIC CONSOLIDATION IN THE FIELD