Design Specifications and Implementation Requirements for State-Level Long-Term Pavement Performance Program

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The procedures for developing a state-level long-term pavement performance (LTPP) program for rigid pavement performance modeling for future pavement management efforts are documented. The program builds on principles already developed for the national-level Strategic Highway Research Program LTPP program. A method used to develop an experiment design that meets current pavement design standards is described. The description of the experimental design is followed by a discussion of the type of data that should be collected. The data items to be collected are divided into two categories: (a) inventory data items and (b) monitoring data items. Inventory data item sources are identified. The human and financial resources required to establish the data base and the resources required to maintain and monitor this data base periodically are reported. In addition to developing the design specifications and implementation requirements for a state-level LTPP program, the implementability of the procedure is evaluated through a case study LTPP program for Texas. The results are an important contribution to providing a basis for collecting the data items needed for the analysis to update current pavement design standards, direct needed research covering climatic and geographic needs, and improve pavement management system efforts overall.

The United States spends approximately $30 billion annually on highway and bridge infrastructure (*1*). This has received considerable attention at the public and private levels, and as a result significant research has taken place at the state and federal levels to address the problems of preserving this large investment.

In spite of the national concern about substandard highway condition, the United States has not systematically studied highway performance since the AASHO Road Test in 1958 to 1960 (*2*). That test was a massive experiment that provided a better understanding of the behaviors of pavements under load applications, but that also left many unanswered questions.

Under the sponsorship of FHWA and with the cooperation of AASHTO, TRB undertook in 1983 a study to investigate the effect of expanded research on improving highway transportation (*3*). The results of the study were reported in *TRB Special Report 202; America's Highways, Accelerating the Search for Innovation* (*3*). That study recommended six important research areas combined under one program called the Strategic Highway Research Program (SHRP).

The SHRP long-term pavement performance (LTPP) program, which has test sections in every state, can be used as a basis for developing a state-level LTPP program. The resulting data base would be used to develop and update distress prediction models, which are the basis of every pavement management system (PMS) and also contribute to revision of current design and construction procedures.

EXPERIMENT DESIGN

The development of distress prediction models is based on the collection of distress data over a period of time. To support the data collection procedures an experiment design is required.

Given the large number of different factors that affect pavement performance, a factorial experiment design needs to be used to ensure that the effects of various factors can be investigated simultaneously. In factorial experiment design procedures the effects of each factor can be studied individually and their interactions with other factors can be examined. More information can be gathered about the true effects, with this methodology, than with experiments that test one factor at a time (*4–6*).

It has been well documented that the performance of continuously reinforced concrete pavements (CRCPs) is affected by moisture, temperature, subgrade swell characteristics, traffic, percent steel, and slab thickness, among others. These variables naturally become candidate factors to be included in a factorial experiment design (Figure 1.)

On the same principles, factorial experiments can be designed for all the pavement types that exist in a state. In summary, the factorial experiment design should accommodate all possible combinations of different variables judged to be of significance for the long-term performance of a particular pavement type.

MAIN FACTORS AND VARIABLES FOR DATA BASE

The manner in which a pavement performs in the field depends largely on the design concepts that were used to generate the pavement specifications. The construction quality and subsequent maintenance and rehabilitation activities carried out after construction to ensure a continuous level of performance comparable to the one when the pavement was new also have significant impacts on pavement performance (*7,8*).

A properly designed data base should provide easy access to processed data and information. The data base should be able to support the development of required models to explain the relationship between significant independent variables and the occurrence of deterioration and distress in the pavements.

To determine these required variables in the data base, empirical and theoretical models need to be analyzed. AASHTO design equations and mechanistic models, representing the two methods respectively, were evaluated to determine the significant variables that affect the performance of rigid pavements. Furthermore, analysis of variance (ANOVA) performed on existing data bases also guided the selection of significant variables (*9,10*).

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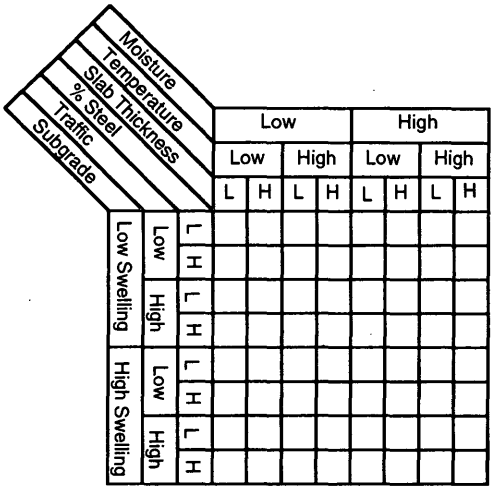

FIGURE 1 Factorial experiment design for CRCP.

TABLE 2 List of Candidate Variables from Mechanistic Models and ANOVA

Variable Type	Variable
Climatic	Temperature Drop
	Moisture Change
Design	Coarse Agg. Type
	Subbase Type
	Slab Thickness
	Traffic (18-kip ESAL)
	Steel Elastic Modulus
	Conc. Elastic Modulus
	Coef. of Load Transfer
Performance	Crack Width
	Crack Spacing
	Traffic (18-kip ESAL)

By evaluating the empirical and mechanistic equations combined with the statistical analysis discussed previously a list of candidate variables that have a significant effect on pavement performance was compiled. The list of candidate variables for rigid pavements on the basis of empirical models and ANOVA is presented in Table 1.

Table 2 lists the candidate variables obtained on the basis of theoretical or mechanistic models.

It can be inferred from Tables 1 and 2 that the data items belong to two broad categories. The first is the inventory data items and the second is monitoring data items.

Inventory data include such data items that remain the same during the monitoring period. There is only a very slight probability that the inventory data will change during the life of the pavement. The inventory data items include information required for the proper identification of the test section, construction material properties, geometric details, environmental conditions, construction dates, and costs. If a rigid pavement is overlaid, usually near the end of its service life, the pavement type then changes to composite pavement, so the inventory data need to be updated to consider these changes (*11*).

TABLE 1 List of Candidate Variables from AASHTO 1986 Design Guide

Variable Type	Variable
Climatic	Temperature
	Moisture
Design	Coarse Agg. Type
	Soil Type
	Subbase Type
	Slab Thickness
	Traffic (18-kip ESAL)
Performance	Roughness
	Cracks
	Patches
	Traffic (18 kip ESAL)

Monitoring data include the variables that change with time, that require periodic evaluation and measurements during the monitoring period, and that require constant updating to keep the data base current. Information concerning distress, serviceability, and deflection measurements should be a part of the monitoring data, which should also include traffic and axle load data. Maintenance and rehabilitation costs incurred during the monitoring period are also included. Data are collected on an annual basis most of the time but could also be based on some other reasonable time period. All this information should be collected in a historical data base required to study the relationship between distress, performance, age of the pavement, traffic and axle loading, and maintenance and rehabilitation procedures.

TEST SECTION IDENTIFICATION AND MONITORING COSTS

The test sections must be located on the ground so that the data collection crews can perform the data collection process adequately. Data collection costs can present a financial burden on the budget within the agency if they are not managed properly. Because of financial constraints priorities should be set to collect required data first and optional data later.

Test Section Identification Costs

The identification and location of the test section physically on the ground remain problems. Some permanent form of test section identification should be used, such as the reflectorized signs being used by the SHRP LTPP program. Besides using these signs, the beginning and end of the test sections should also be marked with white paint. The cost of paint, the manufacturing costs of the sign, and the cost of placing the sign at the proper location combined constitute the test section identification costs.

Inventory Data Collection Costs

State departments of transportation (DOTs) maintain a comprehensive set of project construction plans. Almost all the inventory data requirements can be met from these records and require little or no effort on the part of DOT personnel.

Monitoring Data Collection Costs

Monitoring data to be collected relates to the distress and the performance of the pavement. It also includes the traffic data and deflection measurements required to evaluate behavior. The distress and performance data collection requires visual distress surveys. Deflection measurements require testing with a falling weight deflectometer (FWD) or similar instrument. Traffic data are also collected on a regular basis. Traffic control is required when visual distress surveys and FWD tests are being conducted, and this adds to the data collection cost.

Field Materials Sampling Costs

A comprehensive plan is followed by the SHRP LTPP program to obtain field material samples. Coring and augering are conducted at the test site to collect field material samples (*12*). It is recommended that a similar plan be used to obtain field samples for the state LTPP program. Traffic control will be required while the material samples are being collected.

Traffic Data Collection Costs

To collect detailed traffic data, weigh-in-motion (WIM) stations would be desirable at all the test sections. Data from these WIM sites could be supplemented by the installation of automatic vehicle classifiers (AVCs) at test sections that lack a WIM setup. Detailed weight data are provided by the WIM station for each class of vehicles. Classification data from the AVC device are then supplemented with WIM data from nearby locations to estimate the equivalent single axle loads (ESALs) at a particular site.

Travel Time Costs

Test sections may not be located in every district of the DOT. The size of the state may make travel time an important consideration when scheduling personnel and equipment for data collection. Distances should be calculated along the most direct route to the test section.

Certain other factors such as unforeseen weather, equipment breakdown, the effect of fatigue on personnel efficiency, and the time spent on locating the test section physically in the field on arriving in the general area could not be predicted accurately. To take into account all these factors, the estimated total time was increased by 5 percent (*10*).

Table 3 lists all data collection activities that, when combined, constitute the initial setup costs and the cyclic monitoring costs. Some of these costs are one-time expenses, such as the material sampling and testing and the costs incurred to set up signs for test section identification. Other expenses will be required periodically to maintain and monitor the test sections at a regular interval as selected by the state DOT.

TABLE 3 Activities That Contribute To Test Section Setup and Cyclic Monitoring Costs

Activity
I. Test Section Set Up Costs
Identification signs manufacturing cost
Install test section identification signs
Test section paint details marking
Test section material sampling
First time monitoring
Traffic data collection
II. Test Section Cyclic Monitoring Costs
Test section monitoring
Traffic data collection
Test section maintenance

CASE STUDY: TEXAS LTPP PROGRAM FOR RIGID PAVEMENTS

By using the principles discussed earlier, an LTPP program was developed for rigid pavements in Texas. A factorial experiment design was developed for each of the rigid pavement types in Texas. This sampling template or experiment design was used to select the parameter test sections after the determination of predominant pavement types in each Texas DOT (TxDOT) district. The data items to be collected were determined, and the costs associated with collection of data items were also estimated in terms of man hours required.

Factorial Experiment Design

On the basis of the variable determination procedure described earlier, three experiment designs were proposed, one each for CRCP, jointed plain concrete pavement (JPCP), and jointed reinforced concrete pavement (JRCP). Figures 2, 3, and 4 show the proposed factorial experiment designs for the three pavement types, respectively. The traffic factor midpoint for these experiments is 1.7 million 8.2-ton (18-kip) ESALs/year. A slab thickness of 22 cm (8.5 in.) and an age of 15 years are the respective midpoints for the factors of slab thickness and age in the CRCP factorial experiment design. A thickness of 25.4 cm (10 in.) demarcates between high and low thicknesses for JPCP and JRCP experiment designs.

Data Items To Be Collected

Empirical and theoretical models besides ANOVA on existing Texas data bases (*9,10*) were used to determine the data items to be collected for the Texas LTPP program for rigid pavements. Tables 4 and 5, show the inventory data items and the monitoring data items, respectively, to be collected for the Texas LTPP program.

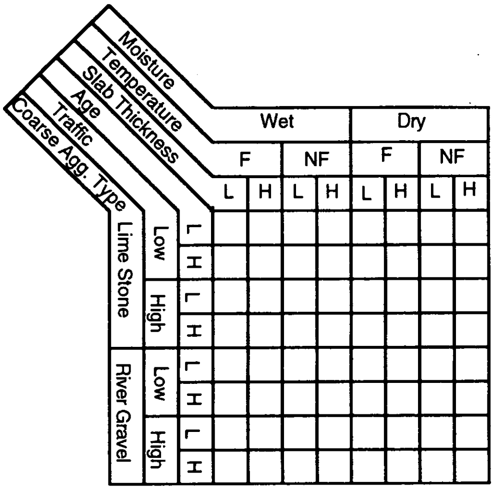

FIGURE 2 Proposed CRCP factorial experiment design for Texas LTPP program.

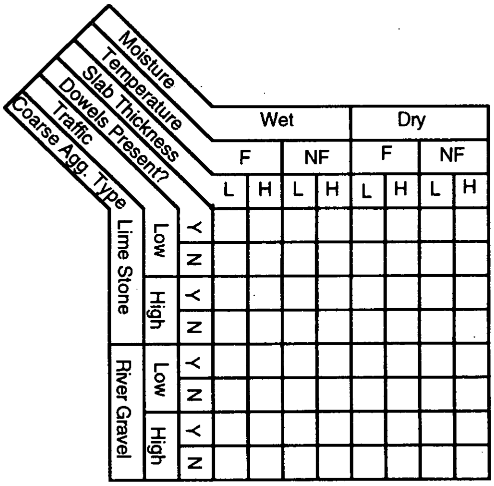

FIGURE 3 Proposed JPCP factorial experiment design for Texas LTPP program.

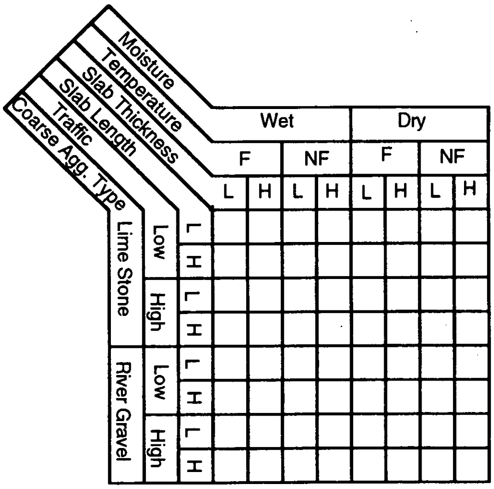

FIGURE 4 Proposed JRCP factorial experiment design for Texas LTPP program.

TABLE 4 Inventory Data Items To Be Collected

Data Type	Data Items to be Collected
Identification	Functional Class of Highway
	Number Designation, Direction
	Pavement Type
	Rural / Urban
	Test Section Location, No. of Lanes
	Construction Date
Geometric Details	No. and Width of Lanes
	Shoulder Presence, Type and Widths
	Drainage Effectiveness
	Joint Spacing
	Dowel Presence, Diameter, Spacing
	Severity and Extent of Existing Distress
Climatic	General Type (Dry Freeze etc.)
	Annual, Monthly Rainfall
	Highest, Lowest Mean Monthly Temperatures
	Freeze Thaw Cycles per Year
	Freeze Index and Thorntwaite Index
Accumulated Traffic	Total and Mean AADT for previous years
	18-kip ESAL, % Trucks
	No., Distribution of Tandem Axles
	No., Distribution of Single Axles
	No., Distribution of Triple Axles
Material Properties	Layer Thicknesses
	Subgrade Soil Type, Classification (especially swelling or not)
	Subbase Soil Type, Classification
	Stabilization Presence, Type
	PCC Moduli of Rupture & Elasticity
	PCC Steel Content, Steel Modulus of Elasticity,
	PCC Coarse Aggregate Type
Accumulated Costs	Initial Construction Cost
	Maintenance & Rehabilitation type, Date Performed and Costs

Test Section Identification and Cyclic Monitoring Costs

TxDOT will carry out all PMS activities in-house with its own personnel and resources. The costs are calculated in terms of the number of man hours, required, and no equipment costs have been estimated.

To manufacture a sign measuring 30 × 38 cm (12 × 15 in.) the cost is approximately $6.00. To put on the white reflectorized paint the cost is usually $5.00. The lettering costs $5.00 per linear meter (3.28 ft). Furthermore, it usually takes two persons half an hour to place the sign in the ground. So, for test section identification purposes the total cost is approximately $18.00 along with one man hour for sign placement in the ground.

Figure 5 shows the average time required to conduct a visual distress survey and FWD testing. The number of man hours required to conduct these activities is given in Table 6.

TABLE 5 Monitoring Data Items To Be Collected

Data Type	Data Items to be Collected
Distress, Performance	Transverse, Longitudinal and Slab Cracking, D - Cracking
	Joint Faulting, Pumping
	Roughness, Patches, Skid Resistance
	Joint, Crack Deterioration
	Lane - Shoulder Separation
Traffic	AADT, Percentage Trucks
	18-kip ESAL for the Time Period
	No., Distribution of Tandem Axles
	No., Distribution of Single Axles
	No., Distribution of Triple Axles
FWD/Deflection Tests	Mean Max. Deflection Under Load
	Deflection Observations, Basin, Loading
	Pavement Temperature

Figure 6 shows the time required to conduct field material sampling. A total of 18 cores are recommended at the beginning and end of the test section (*12*). Table 7 shows the man hours required to obtain field material samples. The cost in man hours required to monitor traffic at a test section is presented in Table 8.

Test sections are not located in all TxDOT districts primarily because not every district has rigid pavements. The size of Texas makes travel time an important consideration when scheduling personnel and equipment for data collection. The data collection party consisting of four persons, two for visual distress survey and two for FWD testing, must travel 11,363 km (7,058 mi.) to collect data. The travel times are calculated at a constant 80 km/hr (55 mph), although most of these are on an Interstate, to compensate for brief stops, for example. A total of 514 man hours must be added to the total time required to complete all the tasks for the network to take into account the time spent in traveling to and from the districts. Table 9 calculates the total man hours required to set up and monitor a total of 100 test sections in Texas.

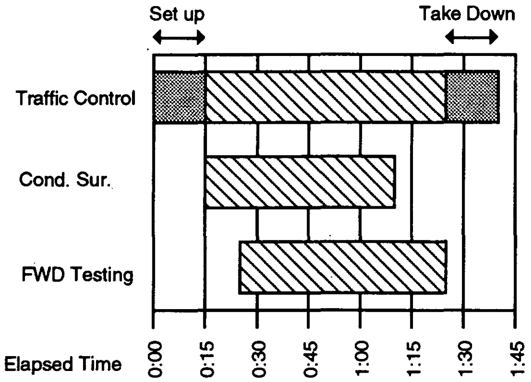

FIGURE 5 Average time required to conduct condition survey and FWD testing.

TABLE 6 Man Hours Required To Conduct Visual Distress Survey and FWD Testing

Testing

Activity	Time Required	Persons Required
Traffic Control	0:30	3
Condition Survey	0:55	2
FWD Testing	1:00	2
Total	2:25	7
Total Cost	**2:25 x 7 =**	**16.92 man-hours**
		17.00 man-hours

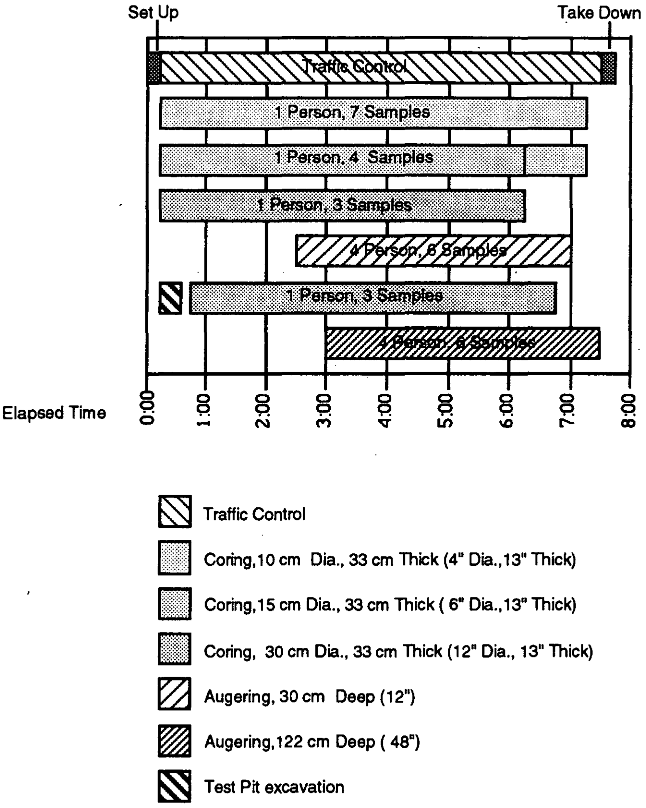

FIGURE 6 Time and persons required to obtain field material samples.

TABLE 7 Man Hours Required To Conduct Materials Sampling

Activity	Time Required	Persons Required
Traffic Control	8:00	3
Coring	8:00	4
Augering	8:00	8
Total	8:00	15
Total Cost	8:00 x 15 =	120 man-hours

TABLE 8 Traffic Data Collection Costs

Method	Man-hours Required
I. portable WIM Site	6 persons X 2 - 8 hour shifts Total 96 man-hours
II. Radian WIM Site	3 persons X 4 - 8 hour shifts Total 96 man-hours
III. Permanent WIM Site	Data down loaded by the Department main frame automatically

CONCLUSIONS

This paper documents a procedure that can be used to set up a state-level LTPP program or to modify or set up a LTPP program in any state or national highway agency. The program is based on guidelines that were originally developed for the national-level LTPP program conducted in the United States beginning in 1987 and continuing under FHWA leadership. Implementation of a state-level LTPP program should provide data that will improve models and thus facilitate better pavement management to safeguard the large investment that each agency makes in its highway pavement infrastructure.

The procedures presented here have been used to develop balanced factorial experiment designs for the predominant pavement types used in Texas. If an agency uses other pavement types, the experiment laid out here will not be applicable, but the procedure can be used to define the experiment design for other pavement types.

If a state is part of the national LTPP program, this may not be sufficient, and indeed probably will not be sufficient to produce a model for direct use in the state, because the national LTPP program is balanced nationally and not within a given state.

TABLE 9 Summary of Test Section Setup Costs and Annual Section Monitoring Costs in Terms of Man Hours Required

Activity	Man-Hours Required per Test Section
Man-Hours Required for Test Section Set Up	
100 Test Sections X 238	= 23,800 man-hours
100 Test Sections X $ 18	= $ 1,800
Travel Time	= 514 man-hours
Climatic Factors (5%)	= 1,216 man-hours
Total	**= 25,530 man-hours plus $ 1,800**
Man-Hours Required for Test Section Monitoring per Round	
100 Test Sections X 115	= 11,500 man-hours
Travel Time	= 514 man-hours
Climatic Factors (5%)	= 600 man-hours
Total	= 12,614 man-hours

One may also find that some of the specifications for developing test sections in the national LTPP study are not applicable to state-level study. In this case one must modify those specifications to accommodate the geographic and climatic needs of an area. Because great thought was given to the national LTPP protocol, however, care should be taken before it is cast aside. In the present study it was determined early that the costs of some of the national LTPP testing protocols were far too expensive for continuation in the long term within Texas. Thus, it was necessary to simplify the effort.

Notwithstanding the conclusions outlined, it is the summary conclusion of the authors that it is possible for any state or other agency to set up an LTPP program within an agency by properly allocating resources and experiment design. Such a well-designed and developed LTPP study should be carried out diligently to provide the core information needed to update pavement management models within the agency. Continuity in the program is far more important than extravagant detail. This is one of the major problems from which the national LTPP study currently suffers.

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