ACCELERATED PAVEMENT TESTING - PHASE I

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16. Abstract

The Arizona Department of Transportation (ADOT) manages an extensive pavement research program that is an integral part of its continuous effort to improve pavement practice and reduce life cycle costs. This study was conducted to evaluate the effectiveness of using accelerated pavement testing (APT) techniques to improve the efficiency and timelines of current pavement research activities. The results obtained confirm that by accelerating the application of loads APT provides an effective means for evaluating pavements in a timely manner. The technique has been used effectively to evaluate the effect of new materials, design features, and construction practices on performance. It is suitable for developing and evaluating potentially innovative techniques for improving pavement analysis and design, and can be used to compare the effectiveness of different maintenance and rehabilitation strategies. Also, APT has been used successfully to develop specifications and mix designs for marginal materials that are incorporated in pavements, and has a great potential for use in developing performance-related specifications. Based on these conclusions a strategic plan was developed for establishing an Arizona APT (AZAPT) program to conduct pavement research in the State. The report provides information on anticipated costs resource needs and logistics, and recommendations for equipment selection, partnerships, and implementation of an AZAPT program. The framework for a strategic research plan for an AZAPT program is also provided.

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METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	2.54	centimeters	cm
ft	feet	0.3048	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	6.452	centimeters squared	cm^2
ft^2	square feet	0.0929	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
mi^2	square miles	2.59	kilometers squared	km^2
ac	acres	0.395	hectares	ha
		MASS (weight)		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		VOLUME		
fl oz	fluid ounces	29.57	millimeters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.0328	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3

Note: Volumes greater than 1000 L shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

These factors conform to the requirement of FHWA Order 5190.1A

*SI is the symbol for the International System of Measurements

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
yd	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
yd^2	kilometers squared	0.39	square miles	mi^2
ha	hectares (10,000 m^2)	2.53	acres	ac
		MASS (weight)		
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1000 kg)	1.103	short tons	T
		VOLUME		
mL	millimeters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

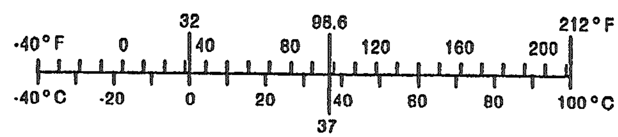


TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1. INTRODUCTION

BACKGROUND

Pavements, like other infrastructure, machinery, and equipment, deteriorate over a long period of time in real life. As a result, testing, evaluation, and validation of new technologies for pavements sometimes require observing their performance over long periods. One key advantage of this approach is the ability to study the interaction between traffic loading, the environment, and aging on pavement performance. Current examples of this approach to pavement testing include the Federal Highway Administration (FHWA) Long Term Pavement Performance (LTPP) study, the mainline portion of the Minnesota Road Research Project (MnRoad), and the Ohio Strategic Highway Research Program (SHRP) Test Pavement.

The disadvantages of in-service pavement studies include the long completion times required before meaningful results can be implemented in the field. Also, while conventional traffic loading on in-service pavements eliminates the cost of special equipment for loading, traffic monitoring to measure the loads applied is often costly and can provide inaccurate data even with the best equipment. Additionally, in many instances it is very difficult to obtain meaningful and concrete results from analysis of the observational data collected from such studies. This is because it is often difficult to obtain data from in-service pavements that fit neatly into an experimental design.

An alternative that has become increasingly attractive in the pavement industry is accelerated pavement testing (APT). By accelerating the application of loads, data for evaluating the effect of new materials, design features, and construction practices on pavement performance can be acquired in a relatively short time. With new materials, design features, and construction practices for pavements being offered frequently, accelerated pavement testing is likely to continue to be one of the most favored methods for testing and evaluating pavements. Also, APT is particularly suitable for the development, evaluation, and validation of potentially innovative techniques for improving pavement design and construction. Such innovative techniques that can significantly increase long-term pavement performance and reduce life-cycle costs continue to be critically important in the pavement industry as funds available for improvements continue to diminish.

With the APT capabilities developed in the west at WesTrack and by the California Department of Transportation (CALTRANS) there are unique opportunities for the Arizona Department of Transportation (ADOT) to participate in APT testing through pooled fund efforts. It may be possible to share the costs for constructing test sections at existing APT facilities, arrange for testing of pavement sections located in Arizona, develop accelerated pavement testing capabilities within Arizona, or combine all of the preceding concepts. This study was conducted to investigate the reasonableness of using APT techniques for pavement research in Arizona, and to determine the efficacy of establishing an APT program in the State to improve further the efficiency and timeliness of current pavement research efforts. If APT techniques were found to be appropriate for application in the state, a key objective of the study was to develop a plan for implementing an Arizona APT (AZAPT) program.

SCOPE

To study the reasonableness of using APT techniques for pavement research in Arizona, it is important to know first what those research needs are. Consequently, the first task of this study involved identifying the key pavement evaluation, testing, and research needs in Arizona. The effectiveness with which the APT techniques currently available can be used to meet those needs was evaluated by examining past practice throughout the world. Of particular interest was the effectiveness of using APT techniques for the following:

- Validating the in-service performance characteristics of current pavement designs by accelerating the evaluation of test sections in the field.
- Validating the performance of new materials and mixes such as Superpave mixes.

- Determining the effectiveness of various maintenance and rehabilitation strategies including surface treatments.
- Developing relationships between pay factors and pavement performance for use in establishing practical pavement performance-related specifications.
- Developing solutions for more effective decision-making in the short term to improve pavement analysis, design, construction, performance and management.

The alternatives available for establishing an APT program to meet these and other pavement research needs in Arizona were evaluated to select the most feasible one. The factors considered include costs, resource needs, possible partnerships, logistics, and funding scenarios. For the most feasible alternative, a strategic plan was developed for implementing an AZAPT program that can be used in ongoing research efforts by ADOT to improve pavement practice.

ORGANIZATION OF REPORT

The report is organized into six chapters. Following this introductory chapter, Chapter 2 of the report identifies the key pavement research needs in Arizona that can benefit from the application of APT techniques. Chapter 3 addresses the effectiveness with which APT techniques have been used in the past to solve pavement evaluation, testing, and research problems. Examples of the effective use of APT techniques to solve specific pavement problems that are of particular significance to Arizona are presented. In Chapter 4, the alternatives available for establishing an AZAPT program are examined. The costs, resource needs, logistics, partnerships, funding scenarios, and other pertinent information for establishing an APT program in Arizona were investigated and the most viable options identified. Chapter 5 provides specific recommendations for establishing an AZAPT program as well as an outline for conducting pavement research using the APT facilities to meet the most pressing needs of the state. The final conclusions and recommendations of this study are presented in Chapter 6.

CHAPTER 2. FUTURE PAVEMENT RESEARCH NEEDS IN ARIZONA

INTRODUCTION

ADOT has an active research program with the goal of improving the state of pavement practice in Arizona. The research conducted includes the development of new technologies and their application to improve pavement performance and optimize the use of the scare funds available. This requires the development of new materials, new designs, improved pavement evaluation techniques, and improved pavement maintenance and rehabilitation techniques. It is envisioned that Arizona's pavement research needs will continue to grow as more and more people move into the state and ADOT is called upon to provide the infrastructure required to meets their needs.

In the continuous effort to develop and maintain a highway system that is efficient, cost-effective, environmentally friendly, and safe, pavement research in the state in the future is expected to cover a wide range of subjects. This will include developing new technologies for maintaining the existing pavement infrastructure as well as research to develop new and improved design strategies for both new and old pavements. This chapter identifies some of the key pavement research needs anticipated in Arizona in the coming years. Specifically, the pavement research needs that could benefit from APT technology are discussed.

KEY RESEARCH AREAS

Some of the key research areas anticipated in the future include the following:

- Validation of current pavement designs following changes such as incorporation of new materials, use of new construction methods, or anticipated changes in traffic loading patterns (e.g., loads, axle types, tire type and pressure).
- Evaluation of the effect of new mixes (e.g., Superpave, stone matrix asphalt, and open-graded mixes); modified conventional materials (e.g., crumb-rubber modified asphalt concrete); and other materials on pavement performance.
- Development of effective maintenance and rehabilitation strategies.

- Development of comprehensive performance-related specifications (PRS).
- Evaluation of the effect of marginal materials and waste materials on pavement performance.
- Development and validation of improved methods and tools for pavement design including rehabilitation.
- Development of tools and techniques for improving pavement performance evaluation and management.

This list includes key pavement research needs likely to be encountered in Arizona during the next decade and that will require some attention fairly rapidly. APT technology presents a unique set of tools for successfully conducting research in these areas to develop results that can be implemented in a timely manner. Following is a summary of some of the specific research anticipated in these areas in the future.

VALIDATING AND IMPROVING CURRENT DESIGNS

Current ADOT designs for new flexible and concrete pavements are primarily based on the 1986 *AASHTO Guide for Design of Pavement Structures*.(1, 2) Arizona uses procedures from the Guide that have been modified to include criteria and adjustments to reflect changes in materials, design concepts, construction methods, and design features in Arizona. These modifications are mostly based on experience and observation of the performance of in-service pavements and the results of previous research in the state. To ensure greater confidence in the current designs and pavements constructed, ADOT periodically conducts research to evaluate the effect of new changes on the current designs. A number of the potential research areas are discussed.

Evaluation of Existing Field Test Sections

There are many pavement test sections that are monitored continually in Arizona as part of ongoing national or local research projects. They include as many as 125 sections built over the years across the state in which ADOT has invested approximately $5 to $6 million dollars. These test sections are a good source of information that can be used to validate in-service pavement performance characteristics and improve current practices.

They include sections that are part of the LTPP study and are periodically monitored in accordance with the study's guidelines. A few of the sections have been overlaid and labeled "out-of-study." However, ADOT monitors the performance of all the sections as part of the state's pavement management program. The data from these two sources present an excellent opportunity to examine the long-term performance of pavements for which detailed design and performance information is available.

Since 1990 ADOT has also constructed many sections to evaluate the performance of various asphalt binders and mix designs. They include sections constructed in accordance with performance based asphalt (PBA) specifications proposed by the Pacific Coast User Producer Group to examine the suitability of suggested asphalt grades for the different climates in the state. Other identifiable sections are test pavements constructed as part of the implementation of the Superpave mix design procedure that will be used to examine the relationship between mix design and cracking and rutting performance. Many other sections in Arizona are also available that provide ample opportunities for forensic evaluation of current designs to investigate particular problems experienced in the field. Field observation and evaluation of all these test sections is expected to continue into the foreseeable future. Analysis of the data and information assembled is an important identifiable research need that will provide ADOT with valuable information to improve current practice.

Effects of Changes in Traffic Loading Patterns and Configurations

One significant area of concern involves evaluation of the effect of changes in traffic loading patterns and configurations on the long-term performance of current designs. Recent trends show that a majority of our pavements will continue to experience higher traffic loading levels.(3) For example, there are current efforts by the trucking industry to get the State to increase the legal load limit for trucks. In the past such increases have often been followed by configuration changes made by the trucking industry and tire manufacturers to increase efficiency in the competitive freight market. These include the introduction of single-out-dual tires or super single tires in place of conventional dual-tire wheel configurations. Also, a growing number of trucks are equipped with lift and/or tag axles fitted with minimum-sized single tires to carry the legal maximum loads.

Such changes result in several benefits to the trucking industry, including reduced tare weight, reduced tire and rim assembly maintenance costs, and improved fuel economy. In contrast there are potential pavement performance problems associated with such changes. For instance, the smaller footprint area offered by a singled-out-dual tire or super single tire is believed by some to result in an increase in the static pavement loading for each tire and rim assembly. However, others believe that the radial spring rates of super singles are substantially lower that those of conventional dual-tire assemblies and lead to lower dynamic pavement loading. The effects of such changes on pavement distress can be substantial, especially in Arizona where high temperatures can cause significant reduction in the modulus of asphalt surfacing layers. Research to evaluate the influence of such changes is necessary to develop solutions to limit the detrimental effects of increased tire loads on pavement performance. The research should quantify the load-damage relationship for the existing pavement designs taking into account the different pavement types used in the state and the load spectra expected.

Incorporating New Mixes in Current Designs

Another area of significant concern involves investigation of the influence of new paving mixes (e.g., Superpave, stone matrix asphalt [SMA], crumb-rubber modified asphalt) on the long-term performance of pavements designed using current design procedures. ADOT places many tons of these mixes for rehabilitation and reconstruction of pavements in Arizona every year. However, the current pavement design procedures do not include explicit provisions for using new paving materials. For example, the current AASHTO-based flexible pavement design procedure does not include structural coefficients for the Superpave, SMA, or crumb-rubber modified mixes used for flexible pavement construction in the state.(1)

Research to develop rational equivalency factors to allow comparison of the new mixes to conventional mixes will extend the range of use of these new mixes. Other potential research areas include work to improve specifications for current mixes and research to determine which of the new mixes are suitable for the load and environmental conditions experienced in Arizona. Specifically, the performance of these mixes in the arid hot-climate of southern Arizona is of interest.

Evaluation of Innovative Construction Practices

Recent tours of European highway agencies touted a variety of innovations in pavement construction and design that have lead to significant improvements in pavement life.(4, 5) A fact that has been less publicized is that many of these innovations have been the result of American ingenuity transported overseas over the years. In many instances, innovations developed locally have not been implemented in the United States because it has not been possible to evaluate them cost effectively. Short of constructing test sections, it has been impossible for most transportation agencies to examine the long-term effects of innovative construction techniques prior to their widespread implementation.

Aside from the cost for constructing test sections, it has been impractical to fully evaluate the effect of innovative construction techniques on long term performance using the traditional method of observing performance under regular traffic loading conditions. With these tradition methods it is often only possible to evaluate the short-term effects of such techniques on pavement performance, which does not always give a full picture. With the increased use of Superpave, SMA, open-graded friction courses, and other large-stone mixes, it will be more important to evaluate various construction techniques and procedures that can improve long-term performance substantially. In fact, there is anecdotal evidence that some of the premature failures of Superpave projects in other states may have their roots in the poor construction practices used. Future research on construction practices anticipated includes work on placement techniques (lift thickness), compaction techniques, compaction temperature, construction methods for longitudinal joints, construction methods for mixes incorporating modified binders, and construction of repairs.

EVALUATION OF NEW MATERIALS AND MIXES FOR PAVEMENTS

ADOT has a comprehensive mix design program to ensure high-quality mixes are used for pavement construction in the state. However, there are indications that the volumetric mix design procedures for Superpave mixes may not necessarily ensure adequate long-term performance in terms of rutting and cracking. Recent results from WesTrack and some construction projects elsewhere have shown that Superpave mixes may experience premature rutting, flushing, and cracking.(6, 7)

As a result of these findings, state highway agencies including ADOT are working to develop comprehensive mix design specifications that include performance tests. These tests, used in conjunction with the Superpave mix design procedure, are needed to validate the long-term performance of the mixes. Efforts currently underway include work in the National Cooperative Highway Research Program (NCHRP) project 9-19 to develop simple performance tests for rutting and fracture for incorporation in the Superpave volumetric mix design method. The goal of NCHRP 9-19 is to develop tests that can also be used for quality control and acceptance of mixes. NCHRP projects 9-16 and 9-17 also have similar objective of developing performance tests both for mix design and QA/QC.

Although considerable progress has been made identifying candidate tests for long-term performance evaluation, there is still a long way to go before specific tests will be available for use in practice. In the meantime, since ADOT is continuing to place over 1/2 million tons of Superpave mixes every year, the department has a pressing need to find a means of testing and evaluating the specific job mixes that are used in Arizona. Moreover, even if the performance tests being developed in national research project become available, research may be necessary to develop calibration factors that are valid for local load and climatic conditions to increase their effectiveness in the state.

An area of research anticipated includes investigations to examine the applicability of the Superpave mix design procedure for designs that do not incorporate neat asphalt (e.g., mixes with modified binders). NCHRP project 9-10 is expected to provide recommended modifications for Superpave binder tests for modified binders later this year. Validation of these recommendations and their effect on performance of the mix designs obtained will be necessary. Similar research will be required for binders with new types of modifiers, combinations of modifiers, and fibers. New mix specifications that include such considerations will be necessary.

Performance tests used to validate or confirm the expected long-term performance of Superpave mixes will undoubtedly improve the reliability of current designs. Research is also required to investigate the failure mechanisms of the mixes that are being placed. These investigations should identify those material properties and volumetric parameters (e.g., density, air voids, gradation, asphalt content) that are significant to the performance of the mixes under Arizona conditions. Such parameters and material properties can be used to develop more accurate performance prediction models for use in pavement management and as design checks.

To a large extent, because of the high costs associated with them, it is likely that most of the fundamental research will be conducted at the national level. However, because of the uniqueness of the arid conditions experienced in the state, it will be necessary to conduct local research to study the deterioration of the specific job mixes that are frequently used in the state under local conditions. The benefits of such research include an increase in the accuracy of any performance prediction models that will be developed for local use.

In addition most of the current efforts at the national level are focused on performance tests for Superpave mixes. However, other mixes and materials that are used in the state include SMA, crumb-rubber modified mixes, open-graded mixes, and a host of other proprietary materials. Future research will be required to investigate the efficacy of using the Superpave mix design procedure for the mix design of these other AC mixes. For these pavement mixes procedures for using the gyratory compactor for mix design have to be developed so that the different mixes can be compared directly. Likewise, research to calibrate the simple performance tests that are being developed will be necessary for the other AC mixes that are used in the state.

EFFECTIVENESS OF MAINTENANCE AND REHABILITATION STRATEGIES

Improved maintenance and rehabilitation strategies will continue to be important as it becomes more and more difficult to fund new pavement construction. To stretch the limited resources available to cover anticipated needs, pressure will continue to mount on engineers to find ways to evaluate and implement innovative and cost-effective maintenance and rehabilitation strategies in the state. The research anticipated in the future in this area includes the following:

- Methods for evaluating the effectiveness of maintenance strategies that include surface treatments, pothole repair, patching, and crack filling and sealing, especially when they involve new materials and construction practices.
- Development and evaluation of innovative rehabilitation strategies for extending the performance lives of existing pavements.

Maintenance Strategies

Improving strategies for maintaining pavements in Arizona will lead to substantial savings. There is ample anecdotal evidence to show that preventive maintenance can be as much as six to eight times more cost effective that major rehabilitation or reconstruction. Research studies to improve or identify good preventive maintenance treatments and strategies are therefore crucial to ADOT's bottom line.

SPR project 371, *Maintenance Cost Effectiveness Study*, is a good example of the kind of research that will continue to be necessary to identify improved maintenance treatments for maintaining pavements in Arizona. In that study various treatments are being monitored and evaluated over a five-year period to determine their performance and cost effectiveness for implementation throughout the state. While important findings for improving current state practice are anticipated, it is unlikely that the results obtained will meet all the future needs of the state. This particular study is investigating a selected set of alternative maintenance surface treatments identified by consensus. It will be essential to periodically conduct research in the future to improve the maintenance practices employed by ADOT to take advantage of future advances in materials design and construction practices.

Research is anticipated in several areas. Work will be required to evaluate the effectiveness of new treatments and improvements in existing treatments. For example, surface treatments are affected by many factors that continually change in the field. These factors include the condition of the existing road, the quality of the materials used, the level of traffic, climatic conditions, and the placement or construction procedures used. Each new or improvement of an existing maintenance treatment type has to be evaluated to determine how its effectiveness is influenced by these factors. Research should be conducted to develop guidelines for application of the maintenance treatments to obtain the best results.

While a majority of evaluations typically focus on the comparative performance of different materials, research is also required to evaluate the influence of the placement or construction procedures used on performance. Recent studies have shown that construction or placement procedures for maintenance treatments can be as significant to long-term performance as the materials types used. Therefore, this aspect of maintenance treatment needs to be reflected in the future research studies.

The overall maintenance strategy for a given roadway is also extremely important to total life cycle cost. Preventive maintenance rather than corrective maintenance should be the significant part of a successful maintenance strategy. Maintenance treatments that are applied without looking at the total picture will not necessarily provide the best results. Investigations of the interaction between different treatments and the timing of treatments that provide the best results in terms of overall life cycle costs is essential.

In all cases, to be cost-effective, the research methods used must allow evaluation and testing of the new maintenance materials, procedures, and strategies in a timely manner. The traditional methods of observing the performance of these maintenance measures over time will not be sufficient to meet all the demands of the future. Therefore, it will be necessary to test these materials, procedures, and strategies using methods with a quick turn around.

Rehabilitation Strategies

Similar to maintenance, rehabilitation of existing pavements will continue to be an important concern in the foreseeable future. As in other parts of the country, there has been an increase in the awareness in the state of the need to find better ways to effectively improve our aging pavement infrastructure. While preventive and routine maintenance play a significant role in extending pavement life, full-scale pavement rehabilitation such as resurfacing is an essential component for keeping the approximately 25,000 lane miles of highways in Arizona in good condition.

Research required in the future will include work to evaluate the effectiveness of the current rehabilitation strategies used in Arizona. An example of such a study is SPR404, *Pavement Performance Evaluation and Rehabilitation Strategies Effectiveness*. A key part of this study was to evaluate the effectiveness of the various overlay design techniques and materials that are used in the state. This study was conducted using the data contained in the state's PMS to retroactively examine the performance of the rehabilitation materials and design used in the past. The results obtained provide valuable information on recommended changes that have to be made to further improve ADOT's pavement rehabilitation program.

Before any the recommended changes are implemented in the field, it will be beneficial to validate the proposed rehabilitation design methods, materials, and strategies. Potential research areas include field validation of improved or new overlay thickness design methods and investigation of the effect of material types and properties on long-term performance. Specific research topics that will be of significant importance include the following:

- Effectiveness of new materials and mixes (e.g., Superpave and SMA) used for overlays.
- Use of waste materials and other by products (e.g., crumb rubber) in asphalt mixes for rehabilitation.

Another potential area of research is the proper timing of rehabilitation measures in association with preventive and corrective maintenance. As indicated previously, more emphasis is currently being placed on rehabilitation solutions that will give the overall lowest life cycle cost and maximum serviceability. Thus, it is not only important to determine which individual materials or designs will be effective for rehabilitation at a particular point in the life of a pavement, the entire rehabilitation strategy that will provide the best results over the life cycle of the pavement is also important.

PERFORMANCE-RELATED SPECIFICATIONS

The development and implementation of performance-related specifications (PRS) is key to the effort to further improve pavement practice in Arizona. Two elements are necessary for a successful PRS. First, there must be tests that can be used to accurately measure key material and construction characteristics that are related to the as-constructed quality of a project. Secondly, there must be quantifiable relationships or mathematical models that relate the as-constructed quality characteristics and other pavement design conditions to long term performance, maintenance strategies, and life cycle costs. These two elements are essential for developing equitable price adjustment schedules that can be used to fairly increase or decrease contractor's fees based on the initial and predicted long-term performance and life cycle costs of their products.

Although there is been considerable progress at the national level on the development of recommendations for PRS, considerable work is still needed to develop a fully functional PRS that can be implemented at the state level. National efforts so far have concentrated on developing a framework for PRS. The framework includes preliminary recommendations on the distress types of importance and the materials and construction quality characteristics that influence them. Recommendations on test procedures and desired levels of the materials and construction characteristics (e.g., asphalt content, air voids for AC, aggregate gradation, air content for PCC, thickness, strength of concrete, smoothness) are also included.(8, 9)

It is anticipated that this framework will be adopted by the states and fine-tuned for local application. It is likely that minor changes will be made with respect to the performance measures, quality characteristics, and levels that will be used in the state

PRS. However, for an effective PRS, research will be required at the local level to identify new test procedures, and material and construction characteristics that may be more representative of local material types, climate and other site conditions. The performance prediction model forms developed through the national research efforts will also need to be calibrated and validated for local conditions. Because of the financial implications of a PRS, this will require high quality data on pavement construction, pavement performance, and maintenance costs. The state's pavement management database will be a good source of such information; however, accelerated pavement testing provides another avenue for obtaining high quality data that can be used with greater confidence to calibrate and validate the performance models. Research involving a combination of evaluation of in-service projects and accelerated pavement testing will provide a better understanding of the pavement construction, materials, performance, and pavement monitoring issues that will improve the PRS for implementation in Arizona.

USE OF MARGINAL, WASTE, AND BY-PRODUCT MATERIALS

With virgin materials becoming scarce, there will continue to be an increase in the use of marginal, waste, and by-product materials in pavements. Such materials can be used in asphalt layers, PCC layers, base/subbase, and embankments or fills. Issues that this raises include the effect of these materials on long-term performance and on the cost effectiveness of the designs in which they are incorporated. Methods for characterizing the properties of such materials are needed to develop inputs for use in pavement analysis and design. Other questions yet to be answered include the development of improved mix design procedures for paving mixtures that include marginal, waste, and by-product materials.

In Arizona, the continued depletion of natural road-building materials is a problem that will in the future require ADOT to contemplate using non-traditional materials for pavement construction. For example, a research project that is scheduled to begin shortly will seek to identify aggregate sources available for construction and maintenance in northern Arizona. Many of the material sources in northern Arizona are located within Indian Nations and are not accessible for use by ADOT. Marginal, waste, and by-product materials present a possible source of road-building materials that will complement the aggregates sources to be identified in this project. Additionally, there is the potential that the aggregates from the newly identified secondary sources, will not be of as high a quality as those from the primary sources from which the state has obtained aggregates in the past.

Accordingly, there is the potential for an explosion in the need for research to assess the quality of such materials for use in pavements. Anticipated research needs will include work to identify the fundamental properties of such materials and to relate them to the key distress types observed in pavements. Tests have to be developed for characterizing the materials to obtain inputs for pavement analysis and design. Because of the varied nature of the materials that fall into this category, in some cases it may even be necessary to develop modified or new procedures for designing mixes that include particular marginal, waste, or by-product materials.

For the marginal, waste, and by-product materials, it is not uncommon to find that even when they satisfy laboratory performance requirements, field validation of their performance is often essential before they can be implemented widely. APT presents a means of conducting field tests to examine the long-term performance of such marginal, waste, and by-product materials. The results from APT can be used to develop guidelines for the widespread use of marginal, waste, and other by-product materials in pavements in Arizona.

IMPROVED PAVEMENT STRUCTURAL ANALYSIS AND DESIGN METHODS

As indicated previously, current ADOT designs for new flexible and concrete pavements are primarily based on the 1986 *AASHTO Guide for Design of Pavement Structures*.(2) Arizona uses procedures from the Guide that include adjustments to account for the effects of local materials, design concepts, construction methods, and design features. While these adjustments have served the state well, periodically the methods and tools used must be revised to incorporate advances and innovations at a more fundamental level. Examples of recent advances in pavement design include improved mechanistic-based pavement analysis procedures, new pavement material characterization techniques, improved design features, and improved mechanistic-based performance models used for checking designs. Research is needed in the state to incorporate these advances into guidelines for the design and construction of long-lived pavements, including rehabilitated pavements.

Implementing a State Mechanistic-Based Procedure for Pavement Design

In the past few years there has been a concerted effort in the industry to move towards the use of mechanistic-based design methods for new pavement and rehabilitation design. For example, a major objective of NCHRP project 1-37 is to develop a national framework for mechanistic-based pavement design to replace the current design procedure in the AASHTO Guide. The results of this research effort are expected to the included in the next AASHTO Guide by the year 2002.

It is anticipated that the mechanistic-based design included in the 2002 Guide will provide a framework for pavement design; but it is unlikely to include specific guidelines for project level design at the local level. Each state will need to conduct research to adapt the procedures developed to their local conditions. Research anticipated in Arizona will include efforts to calibrate, verify, and validate the AASHTO 2002 Guide procedure for local condition when it becomes available.

Some of the features anticipated in the AASHTO 2002 design procedure include the use of traffic load spectra data. Models for checking designs for the occurrence of key distress types will also be incorporated in the design procedure. The models included are expected to be national models developed using data from national databases such as the LTPP database. These models will need to be calibrated and validated for local use or replaced with local models developed using local data. Data obtained using accelerated pavement loading technology is one of the potential cost-effective methods for conducting this kind of research in a timely manner.

Improving Pavement Materials Characterization

Considerable advances have been made in the area of materials characterization for pavement analysis and design in recent years. Different laboratory tests and procedures exist for characterizing the response of the bituminous, cementitious, granular, and soil materials used in pavements. However, questions still remain on which materials characterization procedures and parameters are reliable indicators of long-term pavement performance. Most current design procedures utilize elastic material properties that do not accurately characterize the behavior of the materials in the as-built pavement. Also, rarely are provisions made to account for the influence of field conditions on changes in material properties during service life. While such assumptions have been a source of error in pavement analysis and design, they have been overshadowed by other possible errors associated with the conventional and empirical design methods used.

With the advent of mechanistic-based design methods, however, it will be essential to identify material parameters that better characterize service conditions. The fundamental parameters used must characterize the behavior of the materials not only under the loading, temperature, and moisture conditions expected in service, but must also account for the effects of aging and repeated loading. Without such considerations, the potential improvements offered by mechanistic-based design methods being developed will be compromised by the unreliability of the material parameters used as good indicators of long-term performance. Therefore, a future research need will be to identify performance-related material characteristics for pavement materials that are related to specific distress types and long-term performance. Research will also be needed to develop the procedures and equipments for determining these characteristics.

The NCHRP project 9-19 mentioned previously is addressing some of these issues for flexible pavements. The objectives of that study include the development of simple performance tests for Superpave mixes and an advanced materials characterization model for hot mix asphalt. Research will be needed to evaluate the ability of the simple performance tests recommended by that study to accurately predict the performance of local Superpave mixes as well as other local mixes such as crumb-rubber modified AC and SMA mixes. Likewise, research will be needed to calibrate and validate the materials characterization models being developed to determine their ability to support pavement performance prediction under local conditions.

Another important area of research involves the use of nondestructive testing methods and various backcalculation models to determine material characteristics for the design of rehabilitated pavements. Although there is widespread use of backcalculation procedures and models, the efficacy of these procedures for the different materials that are encountered have not been examined in great detail. Typically, the key material property obtained from backcalculation is the modulus of elasticity. As indicated, for mechanistic-based pavement design involving non-traditional materials such as SMA, gap-graded rubber mixes, or dense-graded rubber mixes other material parameters may be more suitable for use in pavement analysis and design. Research is needed to determine backcalculated material characteristics that are good indicators of long-term performance, and to develop procedures and equipment appropriate for determining such properties for analysis and design of rehabilitated pavement structures.

Recent advances in instrumentation, computer technology, and data acquisition systems have greatly enhanced the capabilities of pavement engineers to perform sophisticated and in-depth analyses of in-situ materials characterization. Utilizing these capabilities, it should be possible to develop improved laboratory tests for characterizing pavement materials. Field calibration of any tests developed will be essential to enable the comparison of laboratory-measured responses to actual responses in the field. APT offers an opportunity to validate any new tests to determine if they can be used to characterize the long-term field performance of pavement materials properly.

Identifying Design Features Beneficial to Long-Term Performance

An important part of pavement design is selection of the design features in addition to the thickness of the paving layers that will improve long-term performance. While this seems obvious, many current design procedures do not explicitly address or give adequate guidance on the selection of design features other than thickness. Thus, many pavements in service often do not include the design features required for good long-term performance.(10, 11) If they are included, the design features are often selected based on empirical data, since there are very few design procedures that include rational methods for analyzing and quantifying the performance of design features. Thus, very much like the AASHTO design procedures they are based on, the current ADOT pavement design procedures do not include explicit provisions for selecting design features other than pavement thickness.

Future improvements of the pavement design procedures used in Arizona should include a means for determining the appropriate design features to use under particular conditions. This will be particularly important if ADOT adopts a mechanistic-based pavement analysis and design method. Research is needed to develop procedures for evaluating the effect of design features on pavement performance in Arizona. These procedures can be incorporated in pavement analysis and design tools used in the State and used to evaluate and select design features to include in new pavement designs. Examples of the design features that can be incorporated to improve performance include drainage system components (e.g., permeable layers, porous pavements), location of layers, shoulder type and construction, load transfer (dowel bar) design, PCC pavement joint sealant design, and reinforcement design.

IMPROVING PAVEMENT PERFORMANCE AND MANAGEMENT

In Arizona, ADOT places considerable emphasis on the evaluation of existing pavements and use of innovative pavement management techniques to determine cost-effective strategies for improving long-term pavement performance. A tool used by ADOT in this endeavor is a state-of-the-art pavement management system (PMS) that has been maintained by the State since 1980. Two of the key components of the PMS are models for predicting pavement performance and tools for generating recommended maintenance and rehabilitation strategies. Also, the PMS incorporates a large database of pavement inventory and condition data. This data is collected with state-of-the-art equipment and must be accurate to reflect the true condition of the roadway network in the state.

Part of ADOT's research program involves work to periodically upgrade the PMS and maintain its effectiveness for assessing the performance of the roadway network and for recommending maintenance and rehabilitation strategies, design techniques, and materials for projects. Previous research has allowed the State to take advantage of new knowledge, the results from many research projects, improvements in analytical methods, innovative materials and procedures for maintenance and rehabilitation of pavements. Similar research will be continued in the future with the goal of maintaining ADOT's high standards in pavement performance and management. Some of the research needs anticipated in the future in accordance with ADOT's overall goal of providing reliable, safe, and cost-effective pavements include the following:

- Improved characterization of the effects of traffic loading on pavement performance under the climatic conditions experienced in Arizona.
- Improved characterization of the effect of vehicle load characteristics (tire type, tire pressure, suspension) on pavement performance.
- Effect of routine and periodic maintenance on long-term pavement performance.
- Development of improved pavement deterioration/performance prediction models.
- Development of models for predicting performance of rehabilitated pavements.
- Improved calibration of pavement evaluation equipment.
- Establishment of criteria for applying the appropriate maintenance and rehabilitation treatments (comparison of performance of different treatments and rehabilitation options).
- Development of tools and techniques for assessing remaining life.
- Evaluation of pavement-vehicle interaction.

SUMMARY

In this chapter the key pavement research needs anticipated in Arizona in the future were described under seven broad categories. As can be expected there are many other research interests of the State that do not fall neatly into any of these categories. Also, as

Table 2.1. Summary of pavement research needs.

Research Need	Potential Study Topics
1. Validating and improving current designs.	1. Evaluating the State's experimental field test sections. 2. Effects of changes in traffic loading patterns and configurations on pavements in Arizona. 3. Performance comparisons to quantify improvements in designs. 4. Evaluating innovative construction practices.
2. Evaluating new materials and mixes for pavements.	1. Field evaluation of performance of Superpave mixes. 2. Evaluation of in-service performance of innovative pavement materials and mixes.
3. Effectiveness of maintenance and rehabilitation practices and strategies.	1. Field evaluation of new maintenance practices. 2. Field evaluation of new rehabilitation practices. 3. Procedure for selecting the best maintenance and rehabilitation strategies.
4. Developing performance-related specifications for Arizona.	1. Identifying significant construction quality evaluation parameters. 2. Calibration of State performance-related specification models.
5. Developing guidelines for use of marginal materials.	1. Quantitative evaluation of marginal, waste, and other by-products. 2. Design recommendations for marginal materials used in pavements.
6. Improving Arizona's pavement design methods for new and rehabilitated pavements.	1. Implementing a State mechanistic-based pavement design procedure. 2. Developing improved pavement analysis procedures. 3. Identifying design features beneficial to long-term performance.
7. Improving performance prediction and pavement management techniques.	1. Validation and calibration of pavement performance models. 2. Validation/calibration of response models. 3. Validation/calibration of backcalculation procedures. 4. Establishing limiting criteria for maintenance and rehabilitation.

a result of changing priorities, it is likely that a different set of research needs may become more essential in the future. However, the information presented can be used as the starting point for developing a strategic research plan to address the important research needs of the State. In accordance with the objectives of this study, emphasis was placed on identifying the research needs amenable to solution using APT technology. Table 2.1 summarizes the objectives of the research needs and identifies the key study topics under each of the seven categories that are anticipated.

CHAPTER 3. EFFECTIVENESS OF APT FOR PAVEMENT RESEARCH

INTRODUCTION

Finding cost-effective solutions to the pavement research needs identified in chapter 2 is paramount to ADOT's overall strategic goals. Much progress is being made using currently available research methods; however, use of APT technology has the potential to greatly improve the success rate and timeliness of specific research efforts in the state. To explore the potential for establishing a successful APT facility in the State, a review of current practice was conducted to examine the effectiveness of using APT to conduct pavement research.

A recently published synthesis of highway practice (NCHRP Synthesis 235) provides an excellent overview of accelerated pavement testing worldwide. However, as indicated by its author, because of limited space not all the information available at the time could be included.(12) Also, as a study to synthesize information on the different APT programs, there was no intent to address in detail the effectiveness of using APT to conduct pavement research, especially with respect to the goals of a typical state highway agency such as ADOT. Accordingly, the synthesis includes information on actual applications as well as proposed applications of the various facilities. Using the information obtained on the specific practical APT applications of interest in this study, this chapter builds on the previous work and addresses the effectiveness of using APT to solve practical pavement problems encountered in Arizona.

The information presented was obtained from several sources. It includes a review of the published literature. Information was also obtained from a questionnaire survey conducted by the research team. The questionnaire shown in appendix A was sent out to a total of 45 potential respondents including agencies that currently own APT facilities, agencies that have owned APT facilities in the past, and agencies and individuals known to have an interest in establishing or developing APT research facilities. Responses were received from 27 agencies and are summarized in appendix B. Finally, information obtained from the web pages of transportation agencies with world-wide-web sites on their APT facilities was also utilized.

TYPICAL APT APPLICATIONS

APT applications can be grouped into two broad categories. The first category includes APT applications to obtain data for validating and improving existing pavement theoretical models and analyses procedures. The other category includes APT applications to find solutions that can be implemented in practice to solve specific, practical pavement problems. An overview of these broad categories of the application of APT is presented in this section.

Pavement Analysis and Design Applications

According to Metcalf past APT applications in pavement analysis have included studies on pavement performance, pavement response, material response, material and layer equivalencies and load equivalencies.(12) The ultimate objective has been to conduct research to support the following:

- Improve and validate theoretical models and pavement analyses techniques.
- Develop instrumentation and data acquisition technologies.
- Improve and validate pavement design procedures in the following areas:
  - Validation and improvement of response models.
  - Validation and improvement of pavement analysis models.
  - Estimation of material layer moduli and validation of models of material behavior.
  - Evaluation and calibration of mechanistic-based long-term performance prediction models.
  - Estimation of pavement life

Of these, the most common use of APT in pavement analysis has been for investigations of pavement behavior. In these experiments and studies, researchers use

APT to investigate and confirm previous theories about pavement behavior.(12, 13, 14, 15). These include examination of the stress-strain, deflection, and deformation response of pavements to applied loads, the effect of load type and position on these responses, and the influence of climate (chiefly temperature) on the responses and corresponding distress and performance measures. The results obtained are used to establish failure criteria for different designs and to investigate performance.

These experiments commonly involve accelerated pavement testing of instrumented sections to obtain response measurements that are analyzed and compared to responses obtained from theory. The theoretical responses are backcalculated using laboratory measured material properties and pavement analysis models. Important by-products of such studies are advances in pavement instrumentation technology and other pavement condition monitoring equipment. Other uses of the results obtained include investigation of materials behavior and validation of the available pavement moduli backcalculation computer programs.(16, 17)

Another area of pavement analysis that has benefited from APT is the development of material and load equivalencies. Some of the early APT tests in Australia involved investigations to evaluate equivalencies of different paving materials. Sharp et al. used the results from APT tests to obtain relative rankings of three different mixes (18). Texas DOT's APT program is also conducting research on load equivalencies, specifically to investigate the validity of the fourth power law. Investigation of the fourth power law was also one of the objectives of the Dynamic Interaction Vehicle-Infrastructure Experiment (DIVINE) conducted using the Canterbury Accelerated Pavement Testing Indoor Facility (CAPTIF), New Zealand.(19, 20, 21)

APT applications in pavement performance have included empirical comparisons of the relative performance of different pavement sections using composite measures such as the Present Serviceability Index (PSI) or direct measurement of distress (e.g., rutting and cracking).(12, 15, 22, 23) In general the objective of such tests has been to use APT to examine or confirm the progression distress according to some established criteria and make changes to existing analysis (and design) procedures based on the information obtained.

Improving Pavement Practice

A majority of the APT facilities have been built to develop results for improving current practice. According to Metcalf the results obtained have been applied in the following broad areas:(12)

- Modification of pavement design procedures.
- Comparison of different pavement configurations.
- Improvement of construction practices.
- Evaluation and improvement of maintenance and rehabilitation practices.

In most instances the APT facilities are built with these specific objectives in mind and several of them have been used for experiments in all the areas. The experiments often involve pavement response and distress measurements on test sections built with the existing design procedures and subjected to anticipated traffic loading conditions. In some instances different environmental conditions have been imposed. Performance is evaluated to provide information on failure modes of typical designs under the controlled loading and used to estimate pavement life in the field. Flaws in the existing design procedure can be detected and the required improvements made. This approach can also be used to extrapolate current designs to special cases, such as for anticipated high load levels that can be simulated with the APT.

Comparison of the relative performance of different pavement configurations also provides useful information for evaluating the effect of new design features. Test sections incorporating new design features such as new materials, stabilized layers, location of layers, drainage layers, fabrics, and others can be tested alongside standard designs. Evaluation of the observed performance and failure modes provides information useful for developing specifications for implementing the new design features in the field. Similarly, new construction practices can be investigated alongside old practices to examine their efficacy. Compaction method, appropriate lift thickness of paving layers, placement of design features, and finishing of surfaces are a few of the construction practices that can be evaluated using APT.

APT has also been used to evaluate maintenance and rehabilitation practices prior to implementation in the field. The approach used is similar to those described previously. The proposed maintenance and rehabilitation practices are applied to test sections and the performances of the repaired pavements are evaluated after controlled loading.

EFFECTIVENESS OF APT IN PRACTICE

To investigate the effectiveness of using APT techniques for the specific applications anticipated in Arizona, the research team reviewed the work of agencies that have owned APT in the past. Information was obtained from published literature and responses to a questionnaire survey that was conducted in this study. Of particular interest was the effectiveness of using APT techniques for pavement evaluation, testing and research including the following:

- Validating the in-service performance characteristics of current pavement designs by accelerating the evaluation of test sections in the field.
- Validating the performance of innovative materials and mixes.
- Determining the effectiveness of various maintenance and rehabilitation strategies including surface treatments.
- Developing relationships between pay factors and pavement performance for use in establishing practical pavement performance-related specifications.
- Other research applications that allow more effective decision-making in the short term to improve pavement analysis, design, construction, performance and management.

Following are results from the evaluation that show that APT techniques have been used extensively by many agencies to effectively solve many pavement evaluation, testing, and research problems. Examples of the effectiveness of APT are provided below.

Validating and Improving Current Pavement Designs

There are several examples that show the effectiveness of APT techniques for validating or improving current agency pavement designs. A typical use of most APT facilities has been performance comparison of standard designs to proposed new designs, either to validate the standard designs or determine whether they can be replaced with the proposed designs to improve performance. Other studies have included evaluation of the effect of changes in service conditions (e.g., loading) on the performance of pavements designed using current methods. Following are specific examples of the effective use of APT in this manner.

South African HVS

A major success of the South African APT program has been the use of heavy vehicle simulators (HVS) to validate and improve pavement designs for over a 20-year period. These were among the primary goals of the South African HVS program when it was started in 1979. Since that time investments in the APT program have totaled about $60 million — a clear indication of the recognition by the highway authorities in South Africa of the effectiveness and benefits of an APT program. A recent evaluation of those benefits put the benefit/cost ratio for all HVS testing in South Africa over the past 20 years as high as 10.(24)

During this period APT has been used effectively in a continuous research program to evaluate, validate, and improve many of the pavement designs used in South Africa. Examples include use of the HVS to evaluate the behavior and performance of bitumen emulsion-treated road bases, designs that incorporate drainage layers or geotextiles, and different concrete pavement designs incorporating different joint seals, reinforcement, pavement support, thickness and load transfer devices. Based on the results obtained from these APT evaluations South African has implemented several design improvements that have resulted in tremendous savings.(25, 26, 27)

Delft LINTRACK

Delft University of Technology in association with the Dutch Ministry of Transport operates a linear APT facility called LINTRACK. LINTRACK has been in operation since 1991 and has been used successfully in several studies to validate the pavement design systems used by the ministry.(14, 28, 29) The tests have been conducted on full-scale test pavements that were constructed using normal construction equipment and paving operations. The capabilities of the facility include the ability to heat the pavement and some measure of moisture control through limiting of the moisture inflow into the pavement and drainage of the subgrade. The tests have conclusively shown the effectiveness with which APT can be used to validate and improve pavement designs.

CAL/APT

The CALTRANS Accelerated Pavement Testing (CAL/APT) program is a joint research and development program between CALTRANS, the University of California at Berkeley, CSIR of South Africa, and Dynatest Consulting Inc. of Ojai, California. CAL/APT has used an HVS to effectively evaluate pavement designs and develop recommendations for improving current designs that have been implemented with considerable success.(30, 31) For example, prior to 1994 CALTRANS required the use of asphalt-treated permeable base (ATPB) in all flexible pavements although the effectiveness of the strategy had not been quantified. Using an HVS a study was conducted to evaluate the performance of ATPB and aggregate bases under traffic loading at moderate temperatures. In these tests CALTRANS was able to quantify ATPB performance relative to other factors such as pavement thickness and mix compaction. The study recommended improved compaction of the AC layer and proper structural design as a means of reducing permeability and as an alternative to including an ATPB layer directly beneath the AC layer. The study also recommended increasing the content of asphalt and modified binders (e.g., asphalt rubber) in the mix design of ATPB as a means of improving resistance to action of water. In cases where ATPB is used, the study recommended the use of filters in the structural section to prevent clogging.(31)

CAL/APT has also successfully used the HVS to study AC mix rutting at elevated temperatures. Variables that were studied included mix type (asphalt concrete and asphalt-rubber hot-mix), tire type (bias-ply and radial dual wheels, wide-base super singles), and lift thickness for the asphalt-rubber hot mix. Initial examination of the results show that under channelized traffic, wide-base supper singles cause more rutting than dual tires. The results obtained at the CAL/APT facility also confirm that compaction during construction is key to obtaining AC pavements with good resistance to cracking. Also, de-bonding of the compacted AC lifts was observed during accelerated testing of AC pavements. Based on these results the research group was able to make recommendations to CALTRANS to increase compaction requirements and to reconsider the use of tack coats to improve bonding between lifts.(32)

It is important to note that using the HVS, CAL/APT was able to obtain the data for these studies within 12 weeks, indicating the effectiveness with which APT can be used to investigate pavement problems quickly.

<u>RIOH ALF</u>

The Research Institute of Highways, (RIOH) China, has used an ALF purchased from the Department of Main Roads, NSW, Australia to conduct pavement research since 1990. Most of the research has focused on asphalt concrete pavements. Investigations conducted include several field tests to evaluate the performance of AC over stabilized base pavement designs that are used in China. The study enabled researchers to validate the performance of these semi-rigid flexible pavements that have been built in China since the 1950's. These pavements are comprised of an asphalt concrete surface course over a stabilized base course, i.e., cement stabilized soil, lime stabilized soil, cement stabilized crushed stone, or fly ash/lime stabilized crushed stone. These pavements have desirable characteristics that include high strength, a smooth surface, and low construction costs. Using the APT facility RIOH was able to evaluate various designs and recommend improvements for extending the performance of these pavement designs that have since been implemented in practice.

Results for Other APT Facilities

Using a circular loading facility, the Swiss Institute of Technology has conducted several accelerated full-scale tests to compare the performance of different pavement designs. The results obtained include improved design and construction methods that prolong life. These results have resulted in specific changes being made to the specifications for new pavements in Switzerland. The CAPTIF facility in New Zealand was used effectively to show that dynamic loading and type of suspension have an influence on pavement deterioration and should be accounted for in current pavement design methods.

Evaluation of Materials and Mixes

In several instances APT has proven to be an effective tool for evaluating the performance of new mixes and modifications of conventional materials and mixes used by highway agencies. Following are examples of the effective use of APT to evaluate materials and mixes and develop recommendations for improving pavement performance.

South African HVS

The South African HVS has been used extensively to effectively evaluate a host of materials that are incorporated in pavement designs to improve performance. The results obtained have led to the development of new specifications and to specific enhancements of South African design manuals including the manuals Structural Design of Pavements (TRH4), Asphalt Mix Design (TRH8), and Materials Selection for Roads (TRH14).

Examples of materials that have been successfully incorporated in designs as a result of HVS tests include the following:(27)

- Water-bound macadam coarse aggregate bases.
- Block paving (masonry and concrete).

- Roller-compacted concrete as a base course.
- Bitumen rubber as an overlay material.
- Styrene Butadiene Rubber (SBR) asphalt in overlays.
- Lightly cement-treated bases.

The HVS also played a major role in the development of a new large-stone mix design similar to SMA that is now used extensively on South African roads. Because of the successes and the effective use of the HVS, South Africa continues to have a substantial APT research program.

LCPC-Nantes

The French LCPC facility has been used extensively in tests to evaluate the performance of various new materials used in flexible pavements in France.(33, 34) The materials that have been studied include hot and cold asphalt mixes for flexible pavements. Research has also been conducted to evaluate the fatigue performance of PCC for rigid pavement. Another key area of research has involved comparison between the field and laboratory performance of materials to determine if the laboratory tests used to characterize the pavement materials provide accurate information representative of service conditions. Based on the results obtained from these studies at the LCPC APT facility, researchers have been able to make several recommendations on new and innovative pavement materials that have been implemented in the field with considerable success. Because of the tremendous success achieved in the past, LCPC anticipates conducting research in the next several years to continue to evaluate cold asphalt mixes, unbound bases courses, and the rutting potential of hot-mix AC for flexible pavements.

CAL/APT

Work has been completed on validation of CALTRANS' rapid-setting concrete pavement mix design for long-life rigid pavements. This study was conducted to evaluate the ability of proposed PCC mixes, made with a wide range of materials and used for rehabilitation construction, to withstand traffic loading 67 hours after placement.

The materials studied included accelerated portland cement and other non-conventional cements that were being considered for rehabilitation during construction windows extending from 10:00 a.m. on Fridays to 5:00 a.m. on Mondays. From the results obtained, CALTRANS was able to develop mix design recommendations for the rehabilitation of concrete pavements on some of the busiest highways in the nation.

Swiss APT

Swiss experience shows the effectiveness of using APT to evaluate and validate the performance of innovative materials and mixes. Over the years the Swiss have used a circular accelerated loading test facility to evaluate the performance of several materials and designs. Materials that have been studied include cement-stabilized materials, cold AC mixes, stone matrix asphalt, stress-absorbing membrane interlayers, and recycled materials. Recommendations from these studies have resulted in specific changes to mix designs that have been incorporated in specifications and used throughout Switzerland.

INDOT-Purdue APTF

Indiana DOT in association with Purdue University runs an accelerated pavement testing facility (APTF). The INDOT APTF is an environmentally controlled facility where pavements can be heated up to 120°F. Initial tests using the APT facility involved research to determine the minimum crushed aggregate requirement for AC mixtures to reduce permanent deformation. The factors evaluated in the study included aggregate type, maximum aggregate size, percent crushed coarse aggregate, asphalt amount, and percent uncrushed sand. The results obtained effectively showed that the progression of rutting in flexible pavements subjected to traffic loading is influenced by the amount of crushed aggregate in AC mixes. The study lead to a recommendation for INDOT to use less than 50 percent natural sand in AC mixes in order to obtain adequate rutting performance.

Using a laboratory wheel track test device (PURWheel), researchers at Purdue University were also able to evaluate the effect of several asphalt additives, modifiers, and fillers on the rutting of flexible pavements. The laboratory APT device proved to be an effective tool for quickly evaluating mixtures with different modified binders. With the APT device the researchers were able to classify the mixtures into those that exhibited performance comparable to unmodified mixtures and those that performed significantly better with respect to rutting. In another study the APT device was also used to develop a test for evaluating the stripping potential of AC mixes. A new Indiana test method (Test Method 583) that was developed based on the results from this study was implemented during the 1997 construction season. These results show that APT can be used effectively to evaluate the performance of new materials and mixes to evaluate their fitness for use in pavements in a cost effective manner.

KSD

The Circular Test Track (KSD) APT facility in Slovakia has been used successfully to test the performance of different aggregates that are used for flexible pavement construction in the country. The APT facility was also used in studies to evaluate the resistance to permanent damage of various asphalt mixtures. Based on the results obtained recommendations were made to the state highway agency on mixes that will improve the performance of flexible pavements. These mixes are now routinely used in flexible pavement construction in Slovakia.

Nottingham PTF

Features of the Pavement Testing Facility (PTF) at the University of Nottingham include controlled conditions for construction and testing of sections. The facility is fully instrumented for evaluating the stress, strain, and temperature in test sections being tested. The APT facility can be used to test different pavement structures arranged in series, although the damaged sections in this arrangement will sometimes tend to influence the performance of adjacent sections. The PTF has proven to be very good for testing deformation sensitive material and has been to assess the performance of various fabrics, grids, and modified mixtures for pavements. It has also been used to evaluate that behavior of lean concrete bases under load. The results obtained have led to recommendations for the use of specific materials in pavement in the United Kingdom to improve performance.

HVS-NORDIC

HVS-NORDIC is a joint APT research partnership formed by the Technical Research Center (VTT) and the National Road Administration of Finland, and the Swedish Road and Transportation Institute. The HVS-NORDIC facility was used successfully in a study of unbound granular base course materials and special bituminous base courses. Another key aspect of the research that is being conducted is the evaluation of alternative materials for use in road construction.

Improved Maintenance and Rehabilitation Strategies

Several successes have been reported of the effective use of APT facilities to develop improved maintenance and rehabilitation strategies that have been implemented by highway agencies.

South Africa HVS

In South Africa the HVS has been used in studies to develop improved strategies for the maintenance and rehabilitation of pavements that have been implemented by various rural and urban road authorities in the country. Successful application of the HVS has included the following:(27)

- Demonstrating the value of preventive maintenance for pavements.
- Identifying and evaluating cost-effective rehabilitation techniques for repairing existing pavements.
- Testing of different rehabilitation options for concrete pavements that have resulted in cost-saving recommendations.
- Developing improved procedures for evaluating pavements for rehabilitation design.

In one study APT was used successfully to evaluate the behavior of various rehabilitation options for cracked-and-seated, semi-rigid pavements.(35) Evidence of the effectiveness of using APT in a timely manner to solve real-life problems is also provided by one particular example. In this particular case it was necessary for the state highway agency to quickly evaluate two options for the rehabilitation of a failed section of a national highway and recommend one for implementation.(36) The options that were being considered were an overlay placed over a bitumen-rubber membrane (stress absorbing membrane interlayers [SAMIs]) and a rubber-modified asphalt overlay, both of which had just been introduced in South Africa at the time.

To evaluate the creep and crack susceptibility of these rehabilitation options, test sections were selected and tested with the HVS at elevated and reduced temperatures. From the in-situ tests the researchers were able to make a rapid qualitative assessment of the rehabilitation options and determine that the designs would fail under traffic loading.(36) This prompted recommendations for changes in the mixtures before they were placed. This provides a very good example of the effective use of APT to evaluate maintenance and rehabilitation strategies within a short time frame. In this case the researchers were able to provide timely recommendations for implementation of the most cost-effective strategy.

LCPC-Nantes

Engineers in France have used the LCPC Nantes circular-track APT facility to effectively evaluate the performance of different maintenance and rehabilitation designs.(33, 34) In one study researchers conducted studies to determine the critical times for preventive maintenance for flexible pavements. Using this facility they were able to make recommendations regarding the best times to perform preventive maintenance on pavements in service. Another study involved a comparison of the performance of pavements incorporating different rehabilitation strategies. The performance of a pavement built with a thick bituminous course from the onset was compared to a thinner pavement that had to be overlaid (rehabilitated) periodically to obtain an equivalent structure. Using APT the researchers were able to test these pavements side-by-side and provided recommendations for the rehabilitation of flexible pavements that have since been implemented.

Australian ALF

The Australian ALF was used successfully in tests to evaluate the performance of different asphalt surfacings used for rehabilitation. The test sections evaluated included thin overlays and a series of asphalt surface treatments. The results obtained pointed to the high sensitivity of the failure mode of these rehabilitation treatments to temperature. The relative deformations under traffic loading of various binders used, including modified binders, were also measured in these tests. The researchers observed that at high temperatures the deformations were mainly confined to the upper asphalt layers. From these results they were able to conclude that only these upper asphalt layers needed to be replaced with a more rut-resistant product when repairs due to rutting are carried out. These conclusions led to significant changes being made in the guidelines for rehabilitation of pavements for rutting damage.

CAL/APT

At the CAL/APT facility the HVS was used to evaluate the performance of two flexible pavement rehabilitation strategies used by CALTRANS. The performance of a conventional dense-graded AC overlay was compared to that of a gap-graded asphalt rubber AC overlay. The overlays were placed on test sections used in a previous APT experiment and were evaluated for reflection and fatigue cracking, as well as rutting at moderate temperatures. The results of the study provided important data that were used to validate CALTRANS' overlay design procedure dating back to the 1960s.

Others APT Facilities

Other reports of the effective use of APT to evaluate maintenance and rehabilitation strategies come from the HVS-NORDIC and KDS test programs in Scandinavia and Slovakia, respectively. The HVS-NORDIC group has reported using their APT facility to evaluate the performance of different maintenance and rehabilitation methods and determine their most effective application times. Also, since not much is know about the life cycle of maintenance and rehabilitation measures that are frequently used, the researchers are using the HVS to examine the deterioration of measures with time. The hope is to develop better procedures and materials for maintenance and rehabilitation of pavements. The KSD APT facility in Slovakia has also been successfully used in the past to evaluate different overlays designs that have since been utilized on Austrian roads.

Performance-Related Specifications

The results obtained from the CAL/APT research program have contributed significantly to CALTRANS' efforts to move towards performance-related specifications. Currently, CALTRANS uses quality control/quality assurance (QC/QA) type specifications to determine AC quantities for acceptance and payment determination. Prior to the CAL/APT program the pay factors used for AC QC/QA were based primarily on engineering judgment. Using the flexible pavement fatigue analysis and design system developed at UCB and calibrated with the HVS, researchers have been able to develop rational pay factors for AC QC/QA that are based on expected performance. These pay factors are being reviewed for implementation by CALTRANS. They are being used on a trial basis for a number of selected projects to obtain data for comparison with the previous pay factors being used by CALTRANS.

Preliminary results from the WesTrack project also shows the effectiveness of using APT to develop PRS for hot mix asphalt. Using the data collected from the WesTrack project, researchers have recently completed the development of a preliminary PSR for hot mix asphalt.(37) The PRS is in the form of an alpha-tested computer program that incorporates two sets of performance prediction models developed with data from the WesTrack project. The basic set of performance predict models are regression models that are used to predict permanent deformation and fatigue cracking as a function of typical material and construction properties such as AC content, in-place voids, volumetrics, aggregate gradation, and initial ride quality. A more advanced set of mechanistic-based performance prediction models is also available that utilize results of laboratory performance tests and relationships developed from the APT WesTrack project to predict fatigue cracking and permanent deformation.

Pay factors for a project can be calculated using either of these sets of prediction models, by comparing the predicted performance and life cycle cost of an as-built project to those of the recommended design. An NCHRP project (9-22) to beta-test the software and improve the range of applicability of the prediction is being planned. A primary objective of that study will be to use a broader range of data, obtained from other APT tests and full-scale field projects and more representative of general conditions, to calibrate and validate the performance prediction models.

Evaluation of Marginal, Waste, and By-Product Materials

Several examples exist of the effective use of APT to evaluate marginal, waste, and by-product materials for use in pavements. These have resulted in recommendations for improved specifications and design of pavements that utilize such materials. Following are examples of some of the successful use of APT in this area.

South African HVS

The HVS has been used in South Africa to effectively test and evaluate the performance of several marginal, waste, and by-product materials. These tests have led to recommendations that have been implemented by the rural and urban transportation agencies in the country. Examples of the materials that have been tested using the HVS include the following: (27, 37)

- Slag used as a granular base course.
- Recycled asphalt base material.
- Emulsion treated recycled granular base material.
- Marginal natural aggregates with various additives.
- Coarse power station generator ash.
- Mine rock dumpings.

In all cases the HVS provided an opportunity for rapid evaluation of these marginal, waste, or by-product materials and a comparison of their performance to those of standard materials. Engineers were able to eliminate from consideration materials that were found to be unsatisfactory and avoid possible costly failures. Also, in several instances, the results led to recommended improvements in specifications to make the materials suitable for road building. For example Rust et al report of HVS tests in 1992 that indicated that a marginal material (decomposed dolerite) could be upgraded to a good base material by the addition of lime and bitumen emulsion.(24) The potential savings from implementation of the results from the HVS tests (which cost about $200,000) was estimated in the order of $30 million for one province alone.

Australian ALF

Studies conducted with the Australian ALF include research to evaluate marginal materials modified by adding bitumen/cement or slag/lime blends to develop indicative performance characteristics as an aid to selecting the most appropriate binder type and proportion. Using the ALF researchers were able to develop guidelines that are based on mechanistic principles and instead of the empirical evidence that were previously used. Another study was conducted to examine the relative performance of blast furnace slag materials (unbound and stabilized) in comparison to crushed rock (unbound and stabilized). The results obtained showed that both unbound and stabilized slag could be used effectively provided they were protected from excessive tensile strains. The study showed that this could be achieved by providing adequate subgrade support and an adequate surface wearing course (preferably asphalt) to prevent surface wear. In another study in 1995 the ALF was used effectively to demonstrate the cost-effective use of flyash in road construction in place of conventional granular (cement stabilized) material.

TRL APT

The TRL APT facility was used successfully in tests to compare the performance of a pavement containing 50 percent recycled material used as a heavy-duty macadam (HDM) base material to an adjacent flexible pavement with a conventional HDM base. The results from the tests showed that for this particular case the recycled pavement performed at least as well as the conventional pavement. This provided the basis for the development of guidelines for the use of recycled materials in pavements.

German PLA

The German Federal Highway Research Institute has a Pulsating Load Applicator (PLA) that it has used over that past 20 years for full-scale flexible pavement tests. It consists of a stationary pulse generator that is used to simulate the vertical component of the forces that are exerted by a wheel load. Its capabilities include equipment for freezing and heating the pavement and the ability to study the effect of a variable groundwater level on test pavements. It was recently used to investigate the feasibility of using recycled materials in the unbound layer of asphalt pavements. Recommendations were developed for use of such materials based on the results obtained from the accelerated pavement testing.

Results From Other APT Facilities

The Nottingham PTF has been used effectively to assess industrial by-products for road bases. The Swiss circular test facility has also been used in accelerated full-scale tests to evaluate different types of recycled roadway materials. The KSD facility in Slovakia was used effectively to evaluate the performance of waste materials such as slag used in place of aggregates. The results from these tests provided valuable information for the development of specifications and recommendations for the used of such waste materials in roadway construction.

Improving Pavement Analysis and Design

Conducting accelerated testing on pavements to improve and validate pavement analysis and design models has been one of the most common uses of APT facilities around the world. The following are specific examples of the effective use of APT in tests designed to provide information for improving pavement analysis and design.

CAL/APT

The CAL/APT facility has been used effectively in several studies to obtain results that are being used to improve pavement analysis and design practice in California. The CALTRANS Longer Life Asphalt Pavement Task Force is using these results to develop recommendations to be implemented in practice. One of the first tests at CAL/APT was a study to validate and improve the fatigue analysis and design procedure developed by UCB. The objective of the study was to determine if the SHRP-developed procedures for mix design and pavement analysis and design could be used to obtain improved AC pavement fatigue performance. Data obtained from accelerated testing of pavement sections with known designs were used to evaluate the effects of asphalt content and air-voids on fatigue cracking response of different asphalt concrete mixes. The results were used to calibrate the flexible pavement fatigue analysis and design system.(30).

Using the calibrated fatigue analysis and design system, the researchers were able to show that "rich-bottom" designs greatly improve fatigue performance. The rich-bottom design is a concept that has been used in Australia during the past decade. It consists of bottom AC lifts with a high asphalt content and compacted to lower air voids to resist fatigue cracking; upper lifts with relatively lower asphalt content are compacted to higher air voids to resist rutting. The research results from the CAL/APT tests provided the basis for the implementation of this design in California. This innovative use of existing materials is expected to prolong pavement life and provide extensive benefits.

The calibrated fatigue analysis and design system was also used to evaluate the effect of binder loss modulus (G*sinδ) on fatigue performance. From the results obtained, a specific recommendation was made to CALTRANS to eliminate the G*sinδ specification from the SHRP PG binder specifications.

In another study, data were obtained to evaluate the assumptions that are included in most of current pavement analysis and design procedures, regarding the effect of different tire types and characteristics on pavement performance. Specifically, the rutting performance of flexible pavements was examined. The effects of bias and radial, super single, and aircraft tires on rutting were studied using a 3-D stress sensor (Vehicle-Road Surface Pressure Transducer Array [VRSPTA]) developed in South Africa. The study was effective in providing information on the stress distributions resulting from tires with these different characteristics. It showed conclusively that the simplifying assumptions of uniform, circular, and normal contact stresses at the tire-pavement interface need to be reevaluated, and provided important information for consideration in pavement analysis and design.

Other studies at CAL/APT that provide evidence of the effective use of APT include one to develop reliability concepts for inclusion in the state's design procedure. These reliability concepts recognize and take into account the variability due to laboratory testing, traffic estimates and construction variables. The facility was also used to determine the failure mechanisms in different pavement layers and for comparison of the fatigue lives of two types of pavement structures. It was also used in a study to quantify the effective elastic moduli of various pavement layers and stress dependency of pavement materials.

South African HVS

The South African HVS program has contributed immensely to the development of new techniques for analysis and design of pavements in the country (39). In particular the fleet of HVS played a major role in the development and validation of the South African Mechanistic Design Method (SAMDM) for the design of new and rehabilitated pavements.(26) Work on the development of the mechanistic-based procedure started back in 1974 and was first comprehensively reported on in a paper by Walker et al.(40) At that stage SAMDM was a simplified design procedure that incorporated transfer functions for predicting fatigue life as a function of the maximum horizontal strain at the bottom of thin AC layers.

Since then the procedure has been gradually improved to incorporate failure criteria for granular base layers and the subgrade, transfer functions for crack initiation of cemented base/subbase materials, transfer functions for thick asphalt base layers as a function of maximum horizontal tensile strain, and criteria for limiting the permanent deformation in the paving layers and subgrade as a function of the vertical compressive strain at the top of each of these layers. Throughout the past 25 years, the continuous improvement of the mechanistic-based procedure into the well-regarded comprehensive SAMDM has only been possible because of the opportunity to extensively test and validate it through accelerated testing of pavements with the fleet of HVS's in South Africa.(26)

FHWA ALF

The FHWA ALF was used effectively in an initial evaluation of the Superpave analysis system and models in the third phase of research at the PTF.(41) The objectives included confirmation that the binder properties identified by SHRP research do indeed significantly affect pavement performance. The primary objective was to show that the Superpave high-temperature performance parameter ($G^*/\sin\delta$) is correlated to the rutting performance of the full-scale test sections, with binders with high $G^*/\sin\delta$ providing greater resistance to rutting. The preliminary results obtained verify the predictive capability of the Superpave rutting parameter for a wide range of binders. It was found that, in general, rutting in the asphalt layer of the test sections decreased with an increase in the rutting parameter.(41)

A good example of the potential of using APT to effectively verify and improve new design and analysis procedures is also offered by the use of the ALF in a study on ultra-thin whitetopping (UTW) of AC pavements. UTW is a rehabilitation technique recently developed wherein a thin layer of high-strength, fiber-reinforced, PCC is placed over a milled surface of rutted and/or cracked AC pavement. The ALF is providing an effective means for quickly validating design equations and models recommended by the American Concrete Pavement Association (ACPA). It is hoped that the data obtained from accelerated tests can be used to evaluate the performance of UTW under controlled loading and temperature conditions and investigate the effect of design features on UTW performance. Without accelerated testing it would take several years to determine if current recommendations for UTW design will provide the desired results.

Nottingham PTF

The strategic goal of the PTF included validation of pavement performance models based on laboratory derived mechanical properties of materials. Specifically models for predicting permanent deformation were evaluated. The APT has also been used effectively in evaluation of the different types of pavement instrumentation. The use of pavement instrumentation is essential for effective pavement research. With the PTF researchers have been able to study the interaction between instrumentation and pavement materials and this has increased confidence in the instruments that are routinely used for pavement research.

LCPC-Nantes

The French have conducted numerous tests using the LCPC APT facility to obtain information and data for improving their pavement analysis and design techniques. Research completed includes studies on the fatigue characteristics of asphalt mixes. The results obtained were used to validate the analytical techniques that are used to model the fatigue behavior of asphalt materials in flexible pavements. Also, the LCPC facility has been used in numerous tests to compare laboratory test results to field performance results. Specific uses of the data obtained include analysis to examine whether laboratory fatigue tests provide an adequate measure of field fatigue failure of asphalt pavements, and to recommend changes to the tests where necessary to simulate conditions under traffic more realistically. The facility has also been used effectively to study measurement methods for stress and strain in pavements, with the goal of developing better equipment and methods for use in the future research to improve pavement analysis and design.

German PLA

The German PLA has been used in the past to compare proposed pavement designs to existing designs before implementation of the former in the field. Examples include a study to determine the equivalency between full-depth asphalt pavement and the standard specified pavement structures that were used previously. This enabled the state highway agency to determine the equivalent full-depth AC designs to use in place of catalogue type designs that had been used for many years. Also, the PLA has been used to investigate the behavior of different construction materials, structural layers, and embankment types (subgrade support) on AC pavement performance. This included investigation of the application of insulating layers for frost protection and the use of expanded polystyrene (EPS) as an insulating base course. Experimental designs using EPS in embankments were also investigated. Findings from the research have been used to improve technical specifications and regulations that are used in Germany to design pavements.

Delft LINTRACK

Research using Delft's LINTRACK to improve pavement analysis and design include tests to validate response models and backcalculation procedures that are used in pavement design. Researchers at Delft are among the few that have done an in-depth study into the code of practice of using APT for pavement research. Based on their initial experience, it became evident that an often forgotten but important aspect of doing research with an APT facility is the development of procedures and protocols for testing and data collection. Issues concerning the appropriate instrumentation, data acquisition hardware and software, laboratory facilities, materials modeling facilities, and protocols for data collection, storage, and analysis have often not been addressed thoroughly. This may lead to the ineffective application of the technology.

Saskatchewan DOT

The Saskatchewan DOT has a full-scale APT facility that has been used in several studies to improve pavement design. Past studies have included evaluation of the effect of subgrade moisture on swelling soils and a study to determine how different pavement layers respond to various loads. The facility has also been used to evaluate the performance of instrumentation embedded in the roadways. Sensors embedded in the track are used to monitor stresses, strains, and movements at various locations and depths. The facility has several unique capabilities that make it well suited for research to improve pavement design. These include the ability to do the following:

- Freeze a portion (1/5$^{th)}$ of the track to simulate freeze-thaw conditions.
- Elevate the temperature of the track to as high as 108°F (42°C).
- Flood the side-slope of a 1/5th of the track to simulate saturation of the subgrade.

- Use a sprinkler system to simulate rainfall.

The results obtained so far have led to significant changes in the design procedure used by the DOT.

Improving Pavement Performance and Management

APT facilities have been used extensively in studies to improve pavement performance and management. A typical use of APT facilities is empirical performance comparisons of different pavement designs to find those that will give better performance under different loading conditions. Also, data obtained from testing of specific pavement designs provide valuable information for validating and calibrating performance prediction models for pavement management uses. Examples of such uses of APT follow.

<u>CAL/APT</u>

Among the first uses of the CAL/APT facility were performance comparisons of different structural designs and overlays.(30) Specifically, CALTRANS designs were examined to determine the effect of factors such as tire type (i.e., bias or radial, super single) on their fatigue and rutting performances. Results of studies conducted so far confirm that one of the key factors that promote good fatigue cracking resistance in flexible pavements is compaction. Also, the study provided valuable information that was used to develop reliability concepts for inclusion in pavement design, as a mean of promoting long life by recognizing the significant effect of the variance in laboratory testing, traffic estimates, and construction variables on design results.

Significant studies in the area of performance conducted at CAL/APT include evaluation of flexible pavements with ATPB, which are required by CALTRANS under all new flexible pavements.(31) From the side-by-side testing on pavements with undrained and drained bases, CAL/APT was able to quantify their performance and determine the failure mechanisms in the different layers of pavements with untreated bases and ATPB. Moreover, the study enabled the researchers to quantify the effects of ATPB on the performance of flexible pavements relative to other variables such as mix compaction and pavement thickness. The results also provided data for evaluation of the effect of stripping damage on flexible pavement performance and reinforced the need to use suitable filters in pavements with ATPB to prevent clogging.

Also mentioned previously was the use of the HVS to calibrate the AC fatigue analysis and design system developed by UCB. The fatigue analysis and design system is able to take into consideration fundamental material properties, level of design traffic, temperature, structure of the pavement, construction and laboratory variability, and an acceptable level of risk. As noted the system calibrated with HVS data has been used in analytical studies to show the importance of construction control and rich-bottom design for AC pavements.

LCPC Nantes

The circular test track at the LCPC APT facility in Nantes has been used in research to improve pavement performance and management in France since 1985. Studies conducted during the first five-year research program using the facility comprised of two stages.(33) The first stage was comprised of tests on pavement sections constructed for the different experimental objectives for which they were originally constructed. This was followed by investigations of the effect of various maintenance treatments on the deteriorated pavements after completion of the initial tests.

Thus, research completed during the first five years included work to confirm and, where necessary, improve the knowledge on pavements analysis and verification of new pavement design methods, as well as verification of overlay design methods, and studies on pavement maintenance strategies and management models. Using the facility, research has been conducted to compare the fatigue and rutting performance of various materials (including hot and cold asphalt mixes) and different pavement structures. The results from tests on flexible pavements were also used to develop improved mathematical analysis models.

FHWA ALF

The FHWA ALF has been used to study the influence of tire pressure and types on pavement performance. With respect to tire type, the FHWA ALF was used to study the impact of wide-based single tires on flexible pavement performance. Data from the ALF were used effectively to validate and calibrate the two rutting models in VESYS 5.(42) The results confirm that rutting models that predict deformation in individual layers are better predictors of rutting that those that predict rutting of the entire pavement system. Similar results have been obtained using long-term performance data obtained from the LTPP study.(43)

Results from Other APT Facilities

Many of the APT facilities identified in this report have been used in various studies to obtain data for improving pavement performance and management. The KSD facility in Slovakia was to evaluate the rutting resistance of asphalt mixtures in an effort to improve performance through selection of the appropriate mixes for specific loading conditions. The Swiss circular APT facility was used in research to evaluate the performance of thin overlays and stress absorbing membrane interlayers. In Finland the NORDIC HVS is being used to study the effects of thawing on pavement performance.

During the early 1980's a small full-scale circular test track constructed in the 1960's by Washington State DOT and Washington State University was used for structural evaluation of flexible pavements and to study studded tire wear. The structural evaluation tests involved studies of the fatigue and rutting performance of the typical flexible pavement sections used in the State.

The Saskatchewan DOT's full-scale APT facility has been used effectively in the past to evaluate the effect of reduced tire pressures on low volume roads and for pavement performance studies to investigate the occurrence of rutting and cracking in typical designs used in the province. The LINTRACK facility at Delft University in the Netherlands has been used in studies to evaluate the performance of pavements and validate existing pavement performance models. The APT facility has also been use to investigate the mechanism of typical distresses including one study to model the phenomenon of surface cracking of AC pavement.

SUMMARY

The results presented in this chapter give conclusive evidence on the effective use of APT by several agencies to address practical pavement research needs. For illustration, Table 3.1 provides specific examples of the effective use of APT to meet research objectives similar to those identified previously in chapter 2 (please see Table 2.1). The examples include the effective use of different types of APT devices to find solutions to pavement research needs similar to those in the seven categories identified for Arizona. They include use of APT to evaluate current designs, new and innovative materials, and to improve pavement analysis and design. In many countries around the world, APT technology has also been used effectively to validate new designs and maintenance and rehabilitation strategies before they are moved into practice. Specifications for the mix design and guidelines for the use of marginal, waste, and other by-product materials have been successfully developed from APT tests before widespread use of such materials. In addition the results from APT tests are being used to obtain data to improve pavement performance prediction and management.

Table 3.1. Effective use of APT for pavement research needs.

Research Need	Potential Research Topics	Evidence of Effective Use of APT
1. Validating and improving current designs.	1. Evaluating the State's experimental field test sections. 2. Effects of changes in traffic loading patterns and configurations on pavements in Arizona. 3. Performance comparisons to quantify improvements in designs. 4. Evaluating innovative construction practices.	1. Implementation of design changes for pavements in South Africa based on APT results. 2. Guidelines for use of ATPB in AC pavements in California. 3. Comparison and validation of standard AC pavement sections in China, South Africa, and Australia.
2. Evaluating of new materials and mixes for pavements.	3. Field evaluation of performance of Superpave mixes. 4. Evaluation of in-service performance of innovative pavement materials and mixes.	1. Incorporation of new materials (e.g., block paving, roller compacted concrete, large-stone mix) in South African pavements 2. Implementation of "rich bottom" designs by CALTRANS. 3. Improved guidelines for CALTRANS's rapid-setting concrete for pavement rehabilitation. 4. Swiss specifications for SMA, CTB, and SAMIs.
3. Effectiveness of maintenance and rehabilitation practices and strategies.	4. Field evaluation of new maintenance practices. 5. Field evaluation of new rehabilitation practices. 6. Procedure for selecting the best M&R strategies.	1. Guidelines for optimal timing of preventive maintenance in France. 2. Guidelines for rehabilitation of AC pavements with thin overlays and surface treatments in Australia. 3. Evaluation of new rehabilitation practices for high-type pavements in South Africa.

Table 3.1. Effective use of APT for pavement research needs.

Research Need	Potential Research Topics	Evidence of Effective Use of APT
4. Developing performance-related specifications.	3. Identifying significant construction quality evaluation parameters. 4. Calibration of State PRS models.	1. Rational pay factors for AC pavements in California. 2. WesTrack alpha-test PRS for HMA.
5. Developing guidelines for use of marginal materials.	3. Quantitative evaluation of marginal, waste, and other by-products. 4. Design recommendations for marginal materials used in pavements.	1. Design guidelines for use of blast furnace slag as replacement for crushed rock in Australia. 2. Design guidelines for use of cement -stabilized fly ash as replacement for granular base in Australia. 3. Guidelines for use of recycled roadway materials (U.K., Germany, Slovakia, Switzerland).
6. Improving pavement design methods for new and rehabilitated Pavements.	4. Implementing a State mechanistic-based pavement design procedure. 5. Developing improved pavement analysis procedures. 6. Identifying design features beneficial to long-term performance.	1. Validation and implementation of a mechanistic design procedure in South Africa. 2. Validation of CALTRANS' overlay design procedure.
7.Improving performance prediction and pavement management techniques.	5. Validation and calibration of pavement performance models. 6. Validation/calibration of response models. 7. Validation/calibration of backcalculation procedures. 8. Establishing limiting criteria for M&R.	1. Verification of outputs of response models. 2. Improved performance prediction models in Australia, South Africa, and the Netherlands. 3. Improved pavement response (deformation) models in U.K. 4. Validation of analytical techniques used to model pavements and materials in France.

CHAPTER 4. ALTERNATIVES FOR AN AZAPT PROGRAM

INTRODUCTION

In chapter 2 the pavement research needs anticipated in Arizona were classified into seven broad categories. While these categories are not all inclusive, they cover a large portion of what can be expected over the next decade. As can be seen from the experiences of other transportation agencies presented in chapter 3, many of these research needs can be addressed effectively using a variety of APT techniques. Establishing the AZAPT program has the potential to provide an effective means for resolving many of the state's pavement research issues in a timely manner. The success achieved will depend on the particular APT technology selected and issues such as the costs, resource needs, logistics, possible partnerships, and funding scenarios associated with the program to be established. This chapter presents the results of an evaluation of the various alternatives available for establishing an APT program for pavement testing, evaluation, and research in Arizona.

The approach used to evaluate alternative APT techniques for the AZAPT program comprised of two stages. In the first stage, the feasible APT techniques that meet the needs of the state were identified. Based on the information and knowledge obtained from the study, these feasible alternatives were evaluated and ranked to determine which technology will be most applicable for pavement testing, evaluation and research in Arizona. With the most feasible APT technology selected, the second stage involved an in-depth evaluation of the alternatives within that category to determine the best APT alternative to recommend on the basis of factors such as costs, resource needs, logistics, potential partnerships, and funding scenarios. This approach streamlined the process for evaluating the various APT techniques. It provides valuable information for implementing the AZAPT program.

IDENTIFICATION OF FEASIBLE ALTERNATIVES

This section describes the analysis that was conducted to identify the feasible alternatives for establishing an APT program in Arizona. The feasible alternatives were evaluated and ranked to determine the technology that will be most applicable to pavement research in Arizona.

Classification of APT Alternatives

As can be seen from the results of the questionnaire survey and the literature review conducted different types of equipment are available for use in the AZAPT program. There is ample evidence that several of these pieces of equipment are being used successfully both in the United States and in several foreign countries. They include programs that use large-scale APT equipment for testing full-scale pavements to small-scale laboratory equipment for laboratory materials testing. The programs with large-scale APT equipment include those that use them in fixed facilities to test pavement sections that are built on location. Others utilize mobile equipment that can be used either on pavement sections built purposely for testing at any location, or that can be moved to particular in-service pavements.

Based on the method of load application and design the different types of APT equipment can be grouped into the following five categories:

1. Full-scale test tracks with loaded trucks (e.g., AASHO Road Test, Westrack, MnROAD).
2. Full-scale fixed, linear tracking mechanical loading device (e.g., INDOT-Purdue APT, LINTRACK)
3. Full-scale fixed, nonlinear (i.e., circular or oval) tracking mechanical loading device (e.g., CEDEX, LCPC)
4. Full-scale mobile, linear tracking mechanical loading device (e.g., ALF, HVS, TxMLS)
5. Devices for small scale laboratory tests (e.g., MMLS, Minnie ALF)

In general, the devices in each category are similar in term of their operation and application for pavement research. However, there can be significant differences between specific types of APT equipment in each category in terms of costs, resource needs, and logistics. For example, although the ALF, HVS and TxMLS are all classified as mobile, linear mechanical loading devices, there are significant differences between their costs, resource needs, logistics, and partnerships with respect to their use in an AZAPT program.

Criteria for Ranking Feasible Alternatives

In the assessment of the type of APT technology to consider for an AZAPT program, there was an initial inclination to look only at equipment with low initial costs since ADOT has a relatively small budget for pavement research. However, it was recognized that the technology with the least initial cost was not necessarily going to benefit Arizona's long-term research needs. Instead the approach was taken to look at a number of key criteria together in order to assess which type of equipment would be suitable for the needs identified. The goal was to use these criteria to rank the different types of APT equipment and identify the APT equipment type that would be most feasible for Arizona's needs. Using this approach it would be possible to reduce to a more manageable number the specific type of APT technologies to examine in detail. The criteria established for ranking the APT technologies included the following:

- Initial costs including cost of equipment, setup, staffing, and startup of operation
- Mobility of APT equipment
- Effectiveness of equipment in previous APT programs
- Applicability of the equipment to Arizona's pavement research needs
- Sustainability of an AZAPT program built around the equipment

For each criterion the research team assigned a score of 0 to 10 (where a score of 10 represents the highest rating and 0 is for the worst case). For each criterion a score of 10 was assigned to the equipment category judged to have the highest rating based on the information obtained from the questionnaire survey and the literature. For that criterion under consideration scores were then assigned to the remaining equipment categories relative to the highest-rated equipment. Following are the basis for assigning the scores under each criterion.

Initial Cost

The main consideration under this criterion was the funds that will be needed to cover the initial costs for basic equipment purchase, setup, and startup of operations. The components that make up this initial cost are different for the various categories. As a group full-scale test track facilities require considerable initial capital outlay before operations can begin. Considerable money is needed up-front to build instrumented test tracks, purchase or lease loaded trucks, and start operations. Consequently, the lowest rating of 1 on a scale of 1 to 10 was assigned to full-scale test track facilities. At the other end small-scale devices used in the laboratory require much less initial capital and were assigned the highest rating of 10. Ratings for the other types of equipment were assigned based on this established scale of 1 to 10.

Mobility

For this category, scores were assigned to account for the advantage of a mobile APT device. There are several advantages to having a mobile loading device for an AZAPT program. For example, use of a mobile APT loading device will permit testing on field or in-service tests sections under a wide variety of climatic conditions. Even if it can be achieved, it is costly to replicate such climatic conditions at a specific location. With several climatic regions in the state, the effects of temperature and moisture on pavements can vary widely across the state. Replicating these conditions at a fixed facility is not only costly, but is bound to limit the variation in conditions that can be studied.

A mobile APT device would also provide opportunities for ADOT to form partnerships with other agencies. Such partnerships will enable agencies to share costs while at the same time allowing each partner to have an independent APT program if desired. APT programs that use facilities at fixed locations necessarily have to involve a lead partner that takes responsibility for operation of the facility on behalf of the other partners. Research programs, timing of specific testing, and retrieval of data often have to be coordinated through this lead partner leading to some loss of control over specific research directions.

Another advantage a mobile APT device offers that is often not recognized is the reduction in the cost for constructing test sections. Test sections for a fixed APT facility have to be constructed at a fixed place with equipment and resources obtained for that particular activity. On the other hand, test sections for a mobile APT device may be incorporated into regular construction projects with minor additional costs, especially when test sections are constructed in the traveled way. Even when a test section is built adjacent to a regular construction project, mobilization costs will be greatly reduced. Thus, with very minor changes a much wider variety of pavement conditions can be included than at a fixed facility. Also, the quality of construction will be more realistic by using test sections built using normal construction procedures in the field.

Effectiveness

This criterion rates the past successes of the different APT loading devices for pavement research and other applications. Scores were assigned based on an assessment of what has been achieved with the different devices. While most agencies tend to consider their APT programs as a successful, particular emphasis was given to published results that have improved highway agency practices. Based on the results obtained in this study, it is clear that the APT programs that use mobile devices have been most success at improving agency practices. Both the HVS in South Africa and the ALF in Australia have been used to make significant contributions in the following areas:

- Validation of current designs
- Evaluation of innovative materials and mixes
- Effectiveness of maintenance and rehabilitation strategies
- Evaluation of marginal, waste, and recycled materials
- Improving pavement analysis and design
- Improving pavement performance

The success of the CAL/APT program since its inception in 1994 is undeniable. While this is partly due to the commitment made by CALTRANS and the excellent efforts of the research team, it is believed that the type of APT equipment selected has contributed enormously to the success achieved.

Full-scale, fixed loading devices have also been used successfully to provide practical results for highway agencies. However, a limitation has been the inability to use these technologies for field tests and the difficulty in translating the results obtained to real-life conditions. Also, a majority of the successes have been in the area of pavement research and not practice. Successful programs include the LCPC program in France and the LINTRACK program the Netherlands.

While full-scale test tracks with loaded trucks have been used successfully in major national research efforts to improve pavement practice, the approach is not feasible for an individual state because of the enormous costs. Also successes tend to be one-dimensional and very focused towards a few specific or limited goals. It is often difficult to change focus and direction if it becomes necessary because of the large effort needed to establish the infrastructure required in the first place. Thus, this approach does not work well if several areas of pavement practice have to be investigated since it becomes too costly.

Applicability

The applicability of the APT technologies to Arizona's future research needs was the key factor rated under this category. Whether the technology can be used to solve the myriad of pavement problems anticipated and outlined in chapter 2 was the primary factor examined. The areas of future research needs examined include the following:

- Validating and improving current designs
- Validating Superpave and other mixes
- Effectiveness of maintenance and rehabilitation
- Developing performance-related specifications
- Developing improved pavement analysis and design methods
- Improving pavement performance and management

- Using marginal, waste and recycled materials.

Sustainability

The factors examined in this category include operating costs, maintenance and repair, ability of transfer the technology developed, and the ability to obtain funding for future operations. The operating costs of test tracks like AASHO, Westrack, and MnROAD are very high and have to be supported at the national level or by pools of states. Most state DOTs the size of ADOT cannot support such an APT program. Maintenance and repair of the equipment and test tracks has to be continuous at these large, fixed facilities and is also very costly. Because they are unique facilities, the maintenance and repairs of facilities such as the LCPC and CEDEX facilities are also very high. Upgrades to the facilities are dependent on the resources of the owner. Relatively smaller facilities are easier to maintain or sustain. Also, it is easier to suspend operations if necessary. While this is not being advocated, equipment such as the ALF, HVS, or TxMLS can always be put in mothballs for a while if that becomes necessary. This can also be done with the smaller fixed facilities such as those at LINTRACK and INDOT-Purdue APT. However, the mobile APT devices (HVS, ALF and TxMLS) have the added advantage of being available for renting out or even selling (as was done by CSIR with the HVS), an opportunity that does not exist for fixed facilities.

Ranking of Feasible Alternatives

The scores assigned to the five distinct types of APT equipment are shown in Table 4.1. The scores for each equipment type were averaged to obtain an average score. The relative ranks of the average scores are shown in the last column of Table 4.1. Based on this ranking the mobile, linear tracking mechanical loading devices ranked highest as the type of APT device desirable for an AZAPT program. This approach provided a good means of selecting the feasible alternatives to investigate more thoroughly from among the large group of APT equipment available for consideration.

Table 4.1. Ranking of feasible alternatives for AZAPT program.

Type of APT Equipment	Relative Score (0-worst rating, 10-highest rating)					Average Score	Relative Rank
	Initial Cost	Mobility	Effectiveness	Applicability	Sustainability		
Full-scale test track with loaded trucks (e.g., AASHO Road Test, Westrack, MnROAD)	1	0	7	7	4	3.8	5
Full-scale fixed, linear tracking mechanical loading device (e.g., INDOT-Purdue APTF, LINTRACK)	8	0	7	8	9	6.2	2
Full-scale mobile, linear tracking mechanical loading device (e.g., ALF, HVS, TxMLS)	4	10	10	10	6	8.0	1
Full-scale fixed, nonlinear tracking mechanical loading device (e.g., CEDEX, LCPC)	3	0	7	6	4	4.0	4
Small scale devices for laboratory testing (e.g., MMLS, Minnie ALF, PURWHEEL)	10	6	2	2	10	6.0	3

EVALUATION OF SELECTED ALTERNATIVES

In the next step of the study the research team focused on evaluating the following mobile, linear-tracking mechanical loading devices available to determine which would be suitable for an AZAPT program:

- South African HVS
- Australian ALF
- Texas MLS

Table 4.2 provides information on the common characteristics of these devices and Figure 4.1 shows the methods of load application for the HVS, ALF and MLS. The following provides information obtained in this study on the costs and resource needs, funding scenarios, logistics, and possible partnership arrangements for establishing an Arizona-based APT program using these devices. The costs provided were obtained from vendors and current users. Information on resource needs, funding scenarios, logistics and partnerships were established based on projections from other those experience at existing facilities.

Background

By all accounts the first of the full-scale mobile, linear tracking APT devices to be put into operation was a prototype HVS that was built in South African in 1970. The first production model ALF built in Australia followed in 1984. The prototype TxMLS was officially accepted by the Texas Department of Transportation (TxDOT) in November 1995. Following is background information of these devices.

South African HVS

The first mobile HVS (a prototype called HVS-II and commissioned in 1970) was based on a fixed linear tracking pavement loading device that was built and used by South African researchers in the late 1960s. A total of six HVS's are now in operation, with two additional units expected to be operational by the end of 2000. Three of the six HVS's are first production units (HVS-Mark III) commissioned in 1978 by the then

Table 4.2. Characteristics of mobile, linear tracking accelerated pavement testing devices.(51)

	ALF	HVS	MLS
Test Loads/Axle(kip) Single/Dual Wheel	9.4 - 37.9	4.5 - 45	6 - 25
Test Wheel Size Single/Dual	11 x 22.5	14 x 20	11 x 22.5
Wheel Speed(mph)	12	8	20
Rep/Hour	380	1200	10 920
Trafficked Length	40	32.8	35
Lateral Displacement of Test Wheels(ft)	2.65	4.9	3
Other Lengths(ft) Testing Transportation	 92.6 98.4	 74.15 74.15	 60 48 + 48
Overall Width(ft)	13.8	12.2	11
Overall Height(ft) Testing Transportation	 22 14.4	 13.8 n/a	 17 13.5
Total Mass(kip)	123	125	130

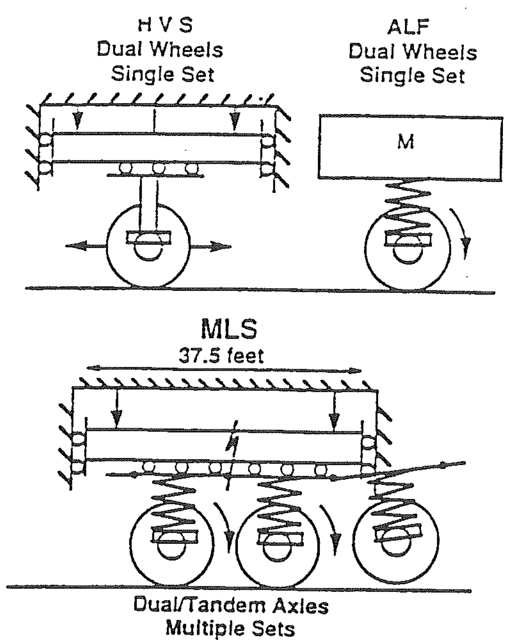
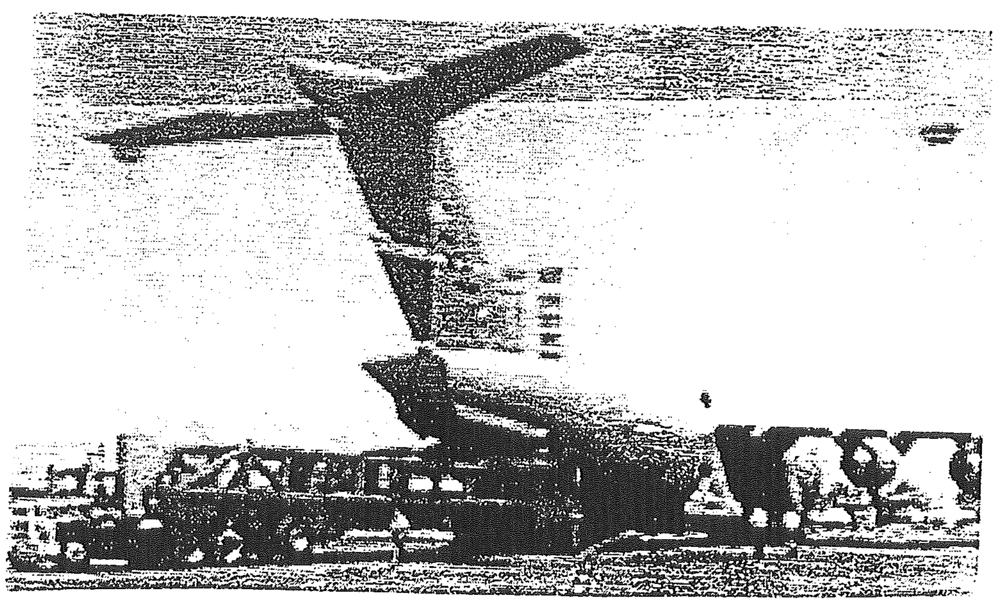


Figure 4.1. Methods of load application of mobile, linear tracking accelerated pavement testing devices.(51)

Council of Scientific and Industrial Research (CSIR) of South Africa. A South African provincial DOT similar to ADOT, Gauteng Department of Public Transport and Roads (Gautrans), owns one HVS. The remaining two were refurbished and sold to CALTRANS in 1994 and are being used in CAL/APT program in California.

The other three operational units are HVS-IVs. The Cold Regions Research and Engineering Laboratory (CRREL) of the US Army Corps of Engineers operates one HVS- Mark IV (Figure 4.2). HVS-NORDIC, a joint research partnership formed by the Technical Research Center (VTT) and the National Road Administration of Finland, and the Swedish Road and Transportation Institute, owns another unit. The Airfields and Pavements Division of the US Army Corps of Engineers Waterways Experiment Station (WES) recently took delivery of an HVS-A. The HVS-A is essentially a bigger version HVS-IV and can apply loads of up to 100 kip in comparison to the maximum of 45 kips for an HVS-IV.

Figure 4.2. CRREL HVS Mark-IV being loaded onto C-17.(27)



According to information obtained during this study, CSIR will soon take delivery of an HVS-IV+, the newest generation of HVS. The Florida Department of Transportation has recently approved the purchase of another HVS-IV+ that will be the eighth HVS in operation when it is delivered. These computer-controlled HVS-IV+ units are fully automated and are capable of applying dynamic loads, an added feature that makes the unit able to simulate traffic loads more realistically.

Australian ALF

The first Australian ALF was designed and manufactured in 1984 by the Roads and Traffic Authority (RTA) of New South Wales, with funding from the National Association of Australian State Road Authorities now called AUSTROADS. This particular ALF, which is currently owned and operated by the Australian Road Research Board Transportation Research Limited (ARRB TR), has been used for a variety of pavement research projects in Australia. In September 1984 the FHWA purchased manufacturing rights for the equipment in the U.S. and in 1986 installed the second ALF at its Pavement Testing Facility (FHWA-PTF) at the Turner-Fairbank Highway Research Center (TFHRC) in McLean, Virginia. The third ALF is owned by China's Research Institute of Highways (RIOH), which bought if from RTA and installed it in 1990. Louisiana Transportation Research Center purchased an ALF in the United States for its Pavement Research Facility (PRF-LA) in 1994. The fifth ALF in operation, the third machine built under license in the US, was purchased and installed in August 1995 by the FHWA at TRHRC in McLean, Virginia. Although the U.S. firm that manufactures the device has ceased operations, an ALF manufactured by RTA of New South Wales can still be purchased through ARRB TR, Australia.

TxMLS

The only TxMLS in existence is a prototype developed for TxDOT by the Center for Transportation Research (CTR) of the University of Texas at Austin and VMW Industries.(44, 45) Development of the prototype took place over a period of about five years. Following several informal acceptance tests of the unit in late 1994 in Victoria, Texas, the unit became operation in 1995 when it was used in the first official TxMLS test program starting in November 1995 at the same location.(46) With the first official tests completed, the unit was being used in a second set of field trials in Forth Worth, Texas in 1999.

Features of Mobile APT Devices

The three mobiles APT devices have several features in common. However, there are many features that are specific to the devices. Following are details of the specific features of the HVS, ALF and TxMLS.

HVS

Having gone through three generations of technological improvements, the current production model HVS is a versatile accelerated loading machine that is now being used by several research agencies and departments of transportation. Table 4.3 shows the key characteristics of the HVS. The models that are now in use include the HVS-III, HVS-IV, and HVS-A. With a maximum load application rate of 32,000 passes (bi-directional) in a day, the HVS-IV and -IV+ can apply up to 1.25 million ESALs per day for the typical 22 kip dual wheel load used for testing pavements.(24) The unit is towed over long distances by hitching it to a truck tractor, but it is also capable of moving under its own power for short distances at a specific site since it has a drive train with wheels that can be steered. This makes the HVS very suitable for testing adjacent test sections.

During the past 20 years since the development of the HVS, CSIR has developed several instruments for measuring pavement response data during pavement testing with the device. They include the following:

- Multi-depth deflectometer (MDD) for measuring deflections within the pavement structure.
- A road surface deflectometer (RSD).
- A laser profilometer for measuring pavement profile.
- A crack activity meter (CAM) for measuring cracks.
- A 3-dimensional stress sensor for measuring stress at the pavement-tire interface.

Table 4.3 Characteristics of HVS. (27)

Type of load	Single wheel or dual wheels
Wheel load	4.5 - 22 kips HVS-III 4.5 - 45 kips HVS-IV, IV+ 10 - 100 kips HVS-A
Direction of Loading	Uni- or bi-directional
Number of passes per day (bi-directional)	19,000 HVS-III 32,000 HVS-IV, IV+
Maximum speed of loading wheels (average)	8 mph (5 mph)
Test track dimensions	Length 20 - 25 ft Width up to 5 ft
Dimensions	Length 74 ft Width 12 ft Height 14 ft
Weight	100 kips HVS-III, -IV, IV+ 220 kips HVS-A

Also, CSIR has compile data from over 20 years of testing with the HVS in South African that provides a large knowledge base for future research studies. Likewise, procedures established for acquiring and analyzing HVS data are available to future users. The availability of such technology from CSIR can shorten considerably the learning curve and setup time for a new APT program.

ALF

A schematic diagram of the ALF is shown in Figure 4.3. It can apply full-scale rolling wheel loads to a test pavement 42 feet long. Test loads between 8 and 25 kips can be applied using the single or dual wheels on a half axle. Aircraft loads of up to 45 kips are also possible. The ALF applies load only in one direction. The load is lifted off at the end of the pavement section and transported to the opposite end for the beginning of another cycle. Able to run at a test speed of up to 12 mph, the ALF can generate up to

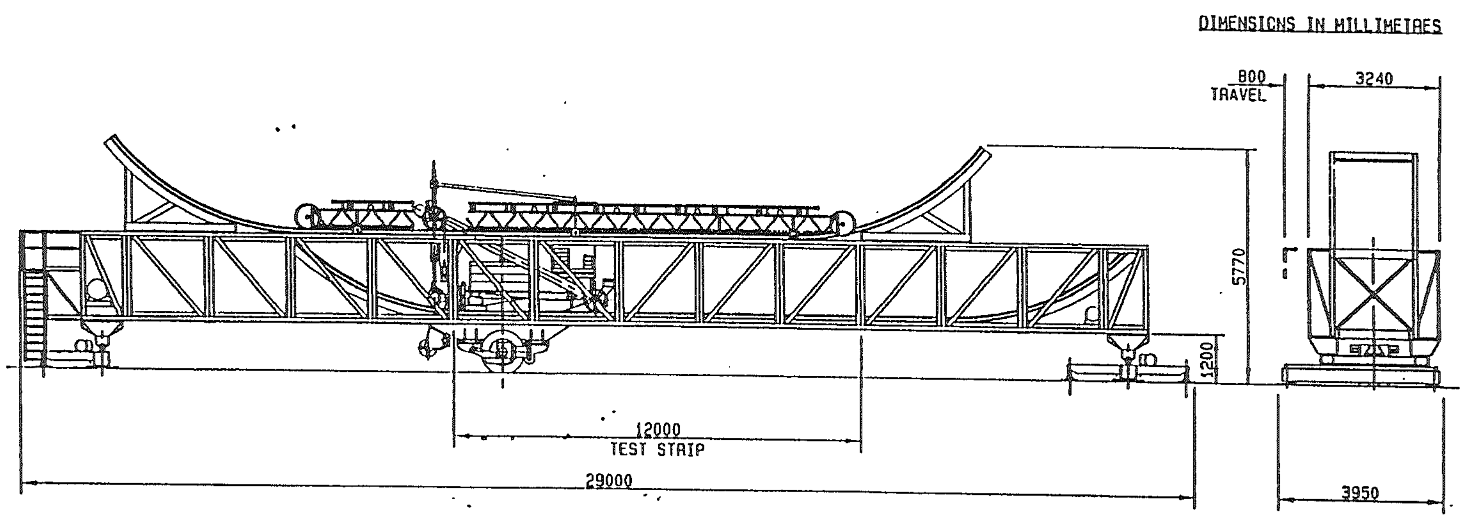


Figure 4.3. Schematic diagram of the ALF. (52)

9,000 cycles of loads per day. Because it is computer controlled, except for stops for schedule maintenance, the ALF can be operated around the clock for 24 hours a day for seven days a week. An operating rate of about 50,000 cycles per week is typical in practice. The ALF is classified as a mobile accelerated loading device that can be moved from place to place for pavement testing. However, for transportation it has to be partially disassembled and loaded onto a flatbed truck in an operation that takes about three working days to complete. Table 4.4 shows some of the key characteristics of the ALF

Table 4.4. Characteristics of ALF.(52)

Test wheels	dual tyre: 12-22.5 Michelin "X" type, ZA pattern, 16 ply rating, tubeless single: 15R22.5 and 18R22.5 tubeless, steel-belted radial
Mass of test wheel assembly	40 kN to 80 kN in 10 kN steps
Suspension for variable mass	air bag and shock absorbers
Power drive to wheel	2 x 11 kW electric geared motors, uni-directional operation, wheels off pavement on return
Transverse movement of test wheels	user programmable; typically a Normal distribution about 1.0 m or 1.4 m wide between outer edges of (dual) tyres
Test speed	nominally 20 km/h
Cycle time	approximately 9.5 seconds
Pavement test length	nominally 12 metres
Site constraints	max. grade: 1-1.5%; max. crossfall: 3%
Operation	automatic control system and fail-safe operation
Portability	readily detachable and transportable
Overall length of ALF	26.3 metres
Overall width of ALF	4.0 metres (operating) 3.2 metres (transport)
Overall height of ALF	5.7 metres (operating) 4.4 metres (transport)
Total mass of ALF	approximately 45 tonne

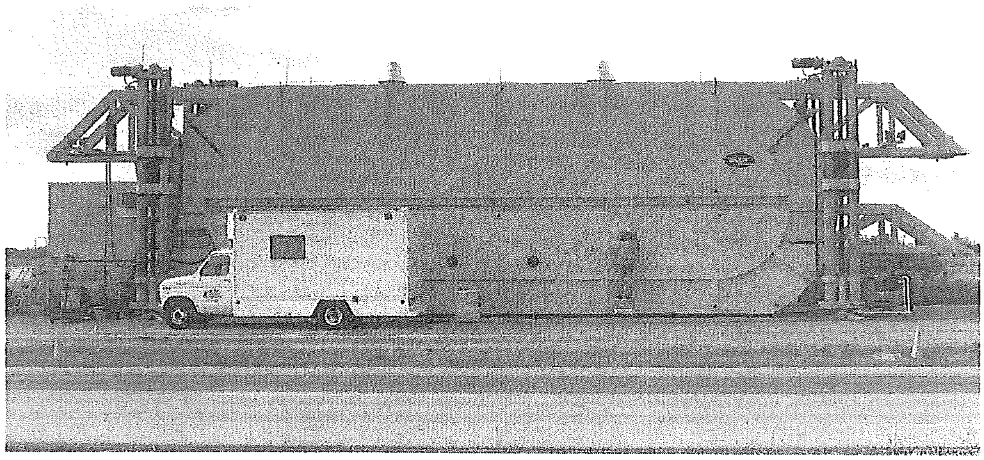
An advantage of the ALF also is the long experience with its use. ARRB TR has used it in over 20 trials at 12 sites in four Australian States since 1984. ARRB TR has compiled a vast database of information from these experiments that can be utilized by future users. Extensive documentation is available on these research projects. Also, the ALF is the equipment of choice of the FHWA, which owns two of the equipment that are being used in several research studies. The results from the research studies conducted with FHWA's ALFs, including field tests at sites in Montana and Wyoming, have been published extensively.(41, 47-50). Experience has also been gained with the ALF owned by LTRC in tests to evaluate different bases course and in a test on rubberized asphalt concrete pavements.(13) Little information is available on the use of the ALF owned by RIOH of China. However, information obtained in this study indicates that the equipment has been use successfully to evaluate the performance of semi-rigid bases in flexible pavements.

TxMLS

The TxMLS is the only mobile accelerated loading device that applies load to the pavement using full-scale axles. Load is applied using six pairs of tandem axles or bogie carriages with a standard 34-kip load on each carriage. A schematic of the prototype TxMLS with the arrangement of its axles is shown in Figure 4.4. Other characteristics of the TxMLS are summarized in Table 4.5. The axles, which are symmetrically placed around a loop, travel in one direction and can be overloaded by about 25 percent. The TxMLS is configured so that any off-the-shelf truck bogie carriage consisting of the chassis frame rail elements, suspension system, axles, wheels and tires can be attached to the unit with minor adjustments. Two of the bogies are powered and the remaining four trail. The TxMLS can be operated at speeds of up to 10 mph and is able to apply a total of 6,000 axle load repetitions in an hour.

For transportation the TxMLS is disassembled into upper and lower units that are transported separately. At the destination the lower half in set in place and the upper half slid back on top and bolted into place. The TxMLS can also be moved for very short distances on a transport trailer to permit measurement of the pavement being tested.

(a)



(b)

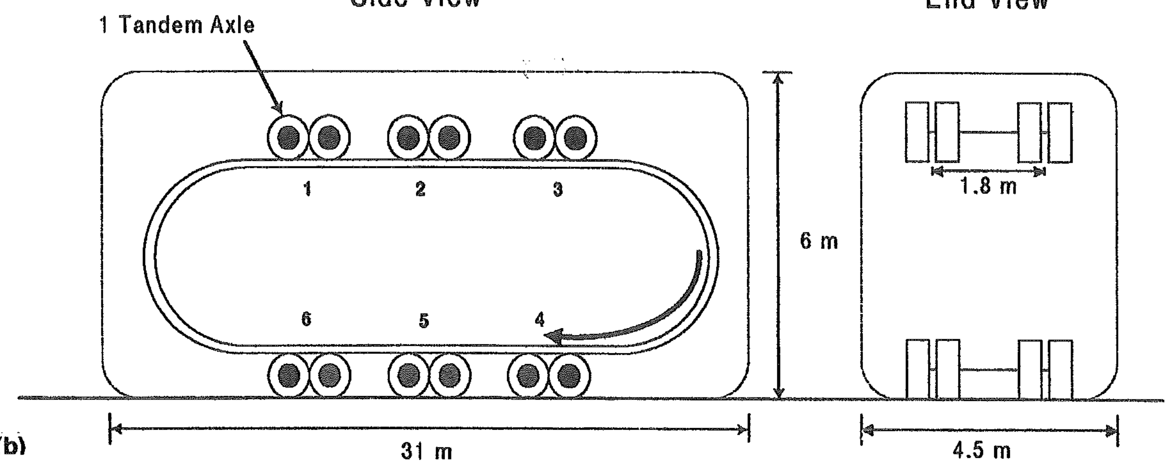


Figure 4.4. Prototype TxMLS and schematic of loading carriages (53)

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Table 4.5. Characteristics of the TxMLS. (12)

PAVEMENT CONFIGURATION	
Testing length/Diameter:	11.1 m traffic length, 26.4 m other testing length
Wheel path width:	0.6 m
Size of test section:	1 or 2 wheel paths at a time
Gantry length:	40m x 3.8m x 4m
Shed size:	N.A
Length of test area:	As needed
LOAD CONFIGURATION	
Wheel configuration:	6 bogies, 12 axles
Wheel load:	Single wheel: 22.2 - 111.2 kN, Dual wheels: 35.6 - 191.3 kN
Wheel suspension:	Standard truck suspensions
Wheel velocity:	32.2 km/hr (usual), 41.5 km/hr (max.)
Wheel passes:	8800 passes/hr (average)
Load propulsion:	Driven axle
Power:	Electrical motor (on two drive bogies)
Housing:	Outside + fixed or mobile
ENVIRONMENTAL CONTROL:	Partial (closed chamber, temperature controlled)

Since it is a prototype the TxMLS has not been widely used except in two field trials. TxDOT completed the first trials in March 1997 on flexible pavement test pads in Victoria, Texas. The second field trials on in-service pavements to evaluate the performance of rehabilitation strategies started in April 1997 in the Forth Worth district. As a prototype the TxMLS is still going through some changes and there is no information on when the first production models will be available.

Cost Items

A sizeable investment is needed to setup an APT program. While the cost items required will differ depending on the type of program, there are a number of common fixed cost items that were identified. These include the initial cost for purchasing the APT device and the annual (or daily) operational costs. Initial purchase costs were obtained from agencies that have purchased APT devices and from manufacturers. These costs provide a good basis for estimating the cost of purchasing an APT for an Arizona program.

Operational costs typically include the cost for running the APT device including energy costs, dedicated technician salaries, routine maintenance costs, major repair costs, and other service contracts. During this study it was determined that in many cases agencies do not keep detailed records of these costs. Moreover, other costs such as those for senior technical staff, research projects, and dissemination of research results are often folded into the operational costs. Because of these reasons it was not possible to ascertain the precise operational costs for the different APT devices under consideration.

<u>HVS</u>

The initial cost of a new HVS was determined to be between approximately $1 and $2 million. The HVS-NORDIC program reported purchasing their new HVS-IV for about $1.7 million and CRREL bought a similar HVS for $1.6 million in January 1997. CALTRANS bought two refurbished units from CSIR for $750,000 each in 1994 for the CAL/APT program. One unit is stationed at the Richmond Field Station (RFS) at UCB and the other is being used on in-service test section on State Route 14 near Palmdale, California. There are plans to contract out use of the later unit to interested highway agencies but no information on rental costs is available at this time. Dynatest Consultants, Inc. is currently the marketing agent for CSIR in the US. Based on the most current information obtained from CSIR, a new HVS-IV can be purchased for about $1.2 million. However, it is estimated that the additional equipment usually sold with the HVS will probably bring the final cost to about $1.6 million.

Operational costs for the HVS depend on the level of use. CSIR reports average operational costs of $1,200 per day for average operations in South Africa excluding personnel costs. For operation of the HVS at their Frost Effects Research Facility (FERF), CRREL reports average operating costs of about $ 1,000 per day excluding personnel costs. Based on the information obtained costs for the fairly extensive CAL/APT research program including personnel costs typically run between $60,000 and $100,000 per month in the field. Specifically, the cost of operations at the Richmond Field Station, including personnel costs, is between $60,000 and $80,000. Both costs do not include the cost of data analysis beyond the first level of data processing. It should be noted that the CAL/APT program uses an older version of the HVS (Mark-III), which has relatively higher operation costs. The newer Mark-IV is highly automated and can be operated with less manpower requirements resulting in slightly lower costs.

ALF

The company with manufacturing rights to the ALF in the US (Engineering Incorporated) has gone out of business, so there is currently no entity that builds the device in the country. However, manufacturing rights for the ALF outside the U.S. are still owned by the Roads and Traffic Authority (RTA) of New South Wales, Australia. RTA built the first ALF that is still used in Australia and the ALF purchased by RIOH of China in 1989. ARRB TR, which owns and operates the Australian ALF on behalf of AUSTROADS and works closely with RTA, estimates the current cost for manufacturing an ALF at about $1.5-2.0 million. The FHWA estimates the current cost of an ALF configured similar to the two being used at the PTF to be about $1.8 million. These units were purchased for $1 million (1985) and $1.5 million (1993). LTRC's pavement research facility reported the cost of their ALF to be approximately $2 million. ARRB TR believes that the cost of an ALF built in Australia may be relatively less.

Estimates of operating costs for the ALF were obtained from several sources. The ARRB TR routinely uses its ALF for contract work and recent clients include several Australian state road authorities (i.e., DOTs), bitumen and asphalt suppliers, slag and fly-ash producers, and the US Army Corps of Engineers. Excluding manpower costs, ARRB TR typically charges $8,000 per month to cover maintenance, spare parts, power, and other equipment costs. LTRC estimates its operational cost per day at about $1,000. Information obtained in this study from the FHWA PTF indicated that operational costs per day for an ALF, including the labor cost for two operators, parts and maintenance, and energy, was approximately $555 per day for tests that were being conducted. This is close to estimates by Bonaquist of between $250,000 and $300,000 including salaries, equipment and supplies, equipment repairs, and replacement parts as the annual operating costs for FHWA's APT program using the two ALFs.(41)

TxMLS

Because it is a prototype there is not much information on the cost of the TxMLS. Total direct expenditures for development of the prototype are estimated to be between $3.0 and $3.5 million. The cost of a production model is estimated at between $2.2 and $2.6 million based on an estimate by Hugo that the prototype would cost about 36 percent more than a production model.(45)

Typical operating costs for the TxMLS are difficult to determine since the unit has been used in non-routine research projects since its development. TxDOT estimates that the annual operating cost for the prototype including personnel cost, maintenance and repair, research support, and service contract (i.e., security, waste removal, heavy hauling) is between $0.85 and $1 million.

Resource Needs

The resources required for running a successful APT program may be classified into two groups. There are common resources that are required regardless of the type of APT technology selected and resources that are dependent on the type of device chosen.

Common Resources

An essential resource required for a successful APT program that is often not given much attention is a strategic research plan developed beforehand that outlines the future work anticipated. The strategic plan should include a test plan covering at least a 10-year period. It should describe in specific detail the work to be done in the first three to five years and provide a general indication of what should be expected for remaining time. Also, because the level of expertise required for a successful APT program is not always readily available, it is important to identify a technical team for the program beforehand. The technical team should include the following people:

- Technicians to operate and maintain the facility.
- Data processing/reduction specialists (could be among technicians).
- Engineers to direct and coordinate testing and analyze data collected.
- Technical advisory committee to provide overall guidance to the program

The number of technicians required will depend on the size of the APT research program desired. However, there should be at least one senior technician dedicated to the operation of the APT device and general management during testing. Other technicians, who report directly to the senior technician, can assist with data collection, repair and maintenance, transportation of equipment, and other such activities. Expertise in instrumentation, data acquisition systems, and the mechanics of the APT device should be available within this group. Also, at least one technician should have considerable expertise in data management and processing because of the large amounts of data generated in an APT program.

The total number of engineers needed to direct and coordinate testing and analyze the data collected will depend on the size of the APT program. A typical arrangement is to appoint a senior engineer to oversee the work, working under the guidance of a technical advisory committee. Additional engineers can be assigned to assist with duties that require considerable engineering expertise. Again, because of the large amount of data generated, an engineer with significant expertise in data management and processing is essential; however, support to assist with data processing can also be provided separately as described previously.

Because of the level of sophistication of the APT devices, training of the technical personnel that will operate the device will be necessary for an AZAPT program. Also, expertise will be required for maintenance and repair of the APT device and other related equipment. Past experience has shown that such training is essential at the beginning of the program so that the staff will become familiar with all technical aspects of and APT program.

Other resources required include equipment necessary for collecting and storing the data from tests. These should include equipment and instrumentation for measuring the following:

- Surface deflection.
- Surface profile.
- Deformation within pavement layers.
- Strains at specific locations within pavement.
- Load at surface and stresses at specific locations within pavement.
- Surface distress progression.
- Pavement temperature and moisture.
- Climatic information.

Procedures and protocols for conducting tests, collecting data, and for data reduction (or first level data analysis) should be clearly defined beforehand.

Device Specific Resources

HVS

A team of at least two technicians is required to operate the HVS. The CAL/APT program typically depends on a technician and an assistant to operate the HVS-III in the field; however, a second assistant is often included to ensure smooth operations. On the other hand, only one technician is assigned to operate the HVS used by CRREL at the FERF laboratory. With automation of the HVS-IV and IV+, it is believed that one technician and an assistant will be adequate for most routine field operations. For extensive field tests two or more teams of technicians that run in shifts can be used.

An advantage of an HVS-based APT program is the availability of ancillary data collection equipment developed by CSIR. The equipment available include the following:

- Road surface deflectometer (RSD).
- Multi-depth deflectometer (MDD).
- HVS laser profiler.
- Crack activity meter (CAM).
- 3D stress sensor.
- Pavement strain transducer (PAST).
- Soil pressure transducer (SOPT).

Agencies that acquire these equipment that have been used by CSIR and other owners of HVS equipment, will have the additional advantage of having available for use technology, data processing, and analysis procedures that have been developed over the years.

ALF

A staff of three to four technicians is required to operate the ALF. According to AARB TR, a team if four was assigned to operate the ALF until recently. Now a staff of three is used for most site operations. The staff should include at least two skilled senior technicians that manage the operation of the ALF. A third person with a good level of technical skill is also desirable but not essential. In a typical operation close to the central office in Melbourne, Australia the ALF is allowed to run unmanned during the night. During the day one senior technician takes responsibility for operation of the unit, routine maintenance and general management of the test site. This technician also conducts basic data processing or data reduction. The other senior technician, assisted by the third technician if necessary, collects all the pavement monitoring data (e.g., FWD, strain gauges, moisture, deflection gauges, and profile data) and provides assistance when the ALF has to be moved on site. Additional staff as necessary conducts extensive data processing and analysis and other duties, such as contract FWD testing. For testing in the field (i.e., outside of Melbourne), two skilled senior technicians accompany the ALF. Temporary staff is hired on an as-needed basis to assist with field operations.

Agencies that operate their ALFs at fixed locations report needing two technicians most of the time. The FHWA reported using two technicians at the PTF site. Also, two technicians one with expertise in instrumentation and the other with expertise in the mechanics of the ALF operate the LTRC ALF. Additional people provide assistance on an as-needed basis on non-recurring duties such as when the ALF needs to be moved. According to the LTRC staff, because the company that manufactured the ALF in the U.S. is out of business, they have had to acquire the expertise for maintenance and repair of the unit over the years.

TxMLS

Information on the resources needed to operate a final production model of the TxMLS is not available at this time. However, the information available on the prototype TxMLS provides guidance on the anticipated needs. At present TxDOT uses a staff of four technicians for operation of the prototype TxMLS. Two teams of four technicians that run in shifts are used for most field trials. The staff is responsible for operating the device, data collection, maintenance and repair, and basic data processing. Research engineers from TxDOT, the Center for Transportation Research at the University of Texas, and Texas Transportation Institute at Texas A&M University presently conduct any in-depth analysis of the data that is required.

Feasible Partnerships and Logistics

General Considerations

Using a mobile, linear tracking device will provide several opportunities for ADOT to form partnerships with other entities. A mobile device permits sharing of the unit while at the same time allowing each partner to conduct an independent APT program if so desired. APT programs that use devices at fixed locations necessarily have to involve a lead partner taking responsibility for operation of the facility at the behest of the other partners. Research projects, timing of specific testing, retrieval of data, and data analysis have to be coordinated through the senior partner. This can lead to a loss of independence that will not be suitable for meeting ADOT's research needs.

A mobile APT device such as the HVS, ALF or TxMLS is particularly suitable for partnership arrangements because of the ease with which they can be transported from place to place. In fact one of the existing units of the HVS is owned and operated by HVS-NORDIC, the joint research partnership formed by the VTT and the Finnish National Road Administration, and the Swedish Road and Transportation Institute. The unit is used in one country one year and then transported to the other country the following year and so on. Not only did the partnership arrangement provide these two relatively small European countries an opportunity to purchase an HVS, they have been able to coordinate their research programs for the benefit of each other. Also, the partnership developed a joint strategic plan for the period 1997-2003 that is currently being implemented.

While any of the mobile APT devices can be used in a partnership arrangement, as noted previously a production model of the TxMLS is not available at this time. Following are the feasible partnership arrangements for an AZAPT program, assuming an HVS or ALF will be the device of choice. These feasible partnership arrangements have been developed based on the information obtained in this study about similar partnerships that have been formed by other agencies.

Arizona-Based Consortium

A local consortium comprised of the DOT and other transportation-related agencies in the State is the most common type of partnership arrangement encountered during this study. Possible partners for such a local consortium in Arizona led by ADOT include the following:

- The State universities.
- Local transportation-related agencies (e.g., Maricopa Association of Governments).
- Highway contractors.
- Materials suppliers.
- Other private industries and local affiliates of national organizations (e.g., America Trucking Association, NAPA, ACPA, PCA).

An example of such a partnership is the CAL/APT program formed by CALTRANS. The CAL/APT program is a joint effort between CALTRANS, UCB, CSIR of South Africa, and Dynatest Consulting Inc. So far funding for the program has been provided directly by CALTRANS, and UCB is in charge of managing day-to-day operations. Because of the unique circumstances in Arizona with reference to the funding available to ADOT for pavement research, a local consortium formed in Arizona will have to include some members that can either contribute or attract funding from private and industry sources, and other sources outside the State.

One feasible arrangement under this plan is a collaborative effort between ADOT and the three public universities as the main partners. As public institutions, the universities offer considerable flexibility in several areas (e.g., manpower and funding) for operation of an APT program that may not be directly available to ADOT. A partnership with the state institutions will open up non-traditional funding avenues that can tremendously reduce the need for ADOT to provide all the funding necessary to support a local AZAPT program. Potential funding sources that can be tapped by the three public universities, either individually or as a group, are described subsequently. Other resources available through the universities include personnel with technical expertise in pavement, materials, geotechnical, mechanical, and electrical engineering. These resources can be used to meet some of the initial needs of an APT program.

A third important category of partners that will make such a collaborative arrangement feasible are other participants from the previous list that have an interest in supporting the research planned. These may include partners able to participate at two levels: participants able to provide funding for the consortium's work and, therefore, with a significant say in its activities, and others that are not able to provide direct financial support. One advantage of a consortium including the universities is the potential of the university to obtain resources from some of these participants that they are not allowed to provide directly to ADOT.

Consortium of Neighboring State DOTs

A second feasible partnership arrangement is a regional consortium of neighboring DOTs. Such a group can pool its resources to purchase an HVS or ALF (e.g., HVS-NORDIC). This substantially reduces the financial burden any one DOT. Two types of partnerships are possible with this arrangement. In one case a consortium can be formed only to purchase an APT device that is rotated between member states and used in individual APT programs with some level of collaboration on research activities. The second alternative is to form a consortium that establishes a single APT program run collectively by its members to meet its common research needs. The potential members for either type of consortia include New Mexico, Nevada, Utah, and possibly Colorado.

Because of proximity, lack of existing APT facilities, interest in establishing an APT program, and similarity in climatic conditions, New Mexico is potentially the best candidate for forming either of such partnerships with Arizona.

Either type of consortium of neighboring state DOTs can also include additional partners such as universities, local governments, private industry, and regional or national trade associations. As indicated an obvious advantage of this arrangement is that the State DOTs can split the cost of running an APT program. A major disadvantage is the loss of independence and identification of the program as a local research program.

Collaboration with an Existing APT Program

The proximity of Arizona to the CALTRANS CAL/APT program provides another feasible option for partnerships. As indicated previously, CALTRANS owns two HVSs and plans to utilize one in collaborative efforts with neighboring states. Consequently, a feasible partnership arrangement is a collaborative arrangement with the CAL/APT program. Several options are available with this arrangement. ADOT (or a local or regional consortium) can contract with CALTRANS to conduct HVS testing in California for specific experiments designed to meet research needs identified in Arizona. Another option would be for ADOT (or a local or regional consortium) to rent an HVS from CAL/APT to conduct research in Arizona. A third feasible arrangement is a combination of the two previous options, i.e., a combination of APT testing conducted by CAL/APT in California and testing conducted locally.

As indicated, the proximity of the CAL/APT program to Arizona is the key advantage of this option. A possible stumbling block is the unavailability of the CAL/APT facilities for such collaborative efforts. It should be noted that these option could also be pursued with the other agencies in the U.S. with APT programs (e.g., FHWA, LTRC, CRREL, and WES). However, based on what is known about the utilization of these APT facilities by these agencies, it is highly unlikely that an AZAPT program can be established that depends on them to find meaningful and timely solutions to the States pavement research needs.

Funding Scenarios and Mechanisms

The funding scenarios and mechanisms for establishing an AZAPT program are examined in this section. The requirements for an APT program utilizing a mobile loading facility include funds for the following:

1. Purchase of loading device and related equipment, i.e., instrumentation, pavement monitoring equipment, and computers for first level processing of data.
2. Initial training of personnel to operate APT loading device and related equipment and startup.
3. Construction of test sites.
4. Operation of loading device and related equipment (excluding personnel)
5. Maintenance, repair, and replacement of facilities
6. Personnel costs for operation of APT facility and pavement monitoring
7. First level data processing, reduction, and storage
8. Engineering analysis of data and reporting of results
9. Implementation of research results.

The types of mechanisms used by APT programs to obtain funds to cover these items were investigated to provide guidance for an AZAPT program. In most cases the key costs were the upfront funds required to purchase an APT device and for startup (i.e., items 1 and 2). Provided an APT program was considered a priority, a substantial part of the other costs or materiel (i.e., items 3 through 9) was often included in the annual research budgets of the program partners. Because of the limited size of funding available in Arizona for pavement research, it is unlikely that ADOT will be a position to fully fund the upfront costs for an AZAPT program. Therefore, the research team also conducted an investigation to identify other possible sources of funding for the unique conditions in Arizona.

The investigations confirmed that in many instances the bulk of the initial funding for APT programs was obtained through the State DOT (e.g., CALTRANS) or other governmental transportation agencies (e.g., FHWA). However, in several instances, additional funds are obtained through DOT-university partnerships. Examples in the United States include the Ohio APLF, NCAT Test Track, Kansas ALT, and INDOT-Purdue APTF. All these programs utilized the flexibility available to universities to solicit funds to initiate their APT programs from various federal, state, local, and private sources.

Mechanisms available through universities to obtain funds to support such a large research effort include direct congressional appropriations, submission of unsolicited proposals to obtain federal funding, and responses to solicitations from U.S. funding agencies. University of Arizona successfully used this approach to recently obtain funding for transportation research. One of the main items that can be funded separately is the mobile loading device estimated to cost between $1 and $2 million. Sources from which funds for specific equipment purchase can be obtained include the following:

- National Science Foundation (NSF).
- Arizona Board of Regents.
- ASU, NAU, and UA research grants.
- Private industry and trade groups

For example, each year the NSF Major Research Instrumentation (MRI) and Instrumentation for Materials Research (IMR) programs assist U.S. institutions with the acquisition or development of major research equipment. A total of $50 million was earmarked for last year's MRI program and awards for equipment ranging from $100,000 to $2 million are expected later this year. Individual U.S. institutions, consortiums led by universities, and partnerships between institutions and private sector partners can submit proposals. Proposals can be submitted for a single equipment or instrument; the maintenance and technical support associated with equipment purchased is also supported.

Another mechanism for obtaining funding is through a pooled fund effort of neighboring states. For example, working with the National Center for Asphalt

Technology (NCAT) at the University of Auburn, Alabama DOT is using this approach to fund a proposed APT program using test tracks. A pooled funded APT program that utilizes a mobile APT device is more likely to be attractive to individual states because of the mobility offered. Such an arrangement would substantially reduce the financial burden on ADOT, and at the same time provide the State with the ability to obtain an APT device for an AZAPT program. If such avenues can be used successfully at least to obtain money for the initial or first year costs, other mechanisms can be used for funding operations in subsequent years.

SUMMARY

This chapter dealt with the alternatives available for establishing an AZAPT to meet the research needs of Arizona identified previously. Based on the needs identified the feasible APT device types available for consideration were classified into the following five categories:

1. Full-scale test tracks with loaded trucks.
2. Full-scale fixed, linear tracking mechanical loading device.
3. Full-scale fixed, nonlinear (i.e., circular or oval) tracking mechanical loading device.
4. Full-scale mobile, linear tracking mechanical loading device.
5. Small-scale laboratory test devices.

Using criteria established for determining which type of APT device meets Arizona's needs, it was concluded that a mobile, linear tracking mechanical loading device such as the HVS, ALF, or TxMLS will be most suitable for use in an APT program. An in-depth analysis of these APT devices was then conducted with emphasis on the features available, costs, resource needs, feasible partnerships and logistics, and funding scenarios and mechanisms. The comprehensive data and information presented on the feasible alternatives provides the basis for the development of the strategic plan for implementing an AZAPT presented in the following chapter.

CHAPTER 5. STRATEGIC PLAN FOR IMPLEMENTING AN APT PROGRAM

INTRODUCTION

The effectiveness of using the available APT technologies to meet specific needs have been addressed and the feasible alternatives available for consideration presented. An in-depth evaluation of the alternatives was conducted and information provided on the possible partnerships that can be formed as well as costs, resource needs, logistics, and funding scenarios. This chapter presents a plan for implementing an APT program for conducting pavement research in Arizona based on an evaluation of these feasible alternatives.

An important observation made during this study was the essential need for a plan for pavement research to be developed prior to the purchase of the tools required for an APT program. Many APT programs failed because not much emphasis was placed on the development of the test plan. As such a preliminary outline for a strategic research plan for conducting pavement research in the AZAPT program is provided. It is intended as an initial roadmap for a more comprehensive research plan to be developed in phase II of this research project following approval to proceed with the establishment of an AZAPT program.

SELECTION OF RECOMMENDED APT DEVICE

Assessing the information compiled in this study, a South African HVS is recommended as the best APT loading device for an AZAPT program. The key reasons for this selection include the following:

1. The HVS has a long track record of successful use in APT programs both in South Africa and the United States. HVS units have been in operation since the early 1970s when the first production unit was commissioned in South Africa and there is considerable historical data that will be beneficial to an AZAPT program.
2. A key limitation of APT programs recognized in this study is the lack of documented procedures and protocols prepared prior to the implementation of the program.

Procedures and protocols regarding constructions of test sections, instrumentation, data acquisition, and data analyses are very important to the success of an APT program. The HVS has over 25 years of testing experience associated with it and offers considerable information for potential users. Part of the data collected is contained in a recently released CD-ROM multimedia presentation that includes examples of data obtained with the HVS.

3. The mobility of the HVS provides the user with an option that is not available with the other APT facilities. Not only can the HVS be used on pavement sections constructed specifically for testing, it also can be used to test in-service pavement sections. This makes it possible to conduct impromptu testing of pavement sections at any location on short notice.

4. During the past 20 years CSIR has developed other ancillary pavement monitoring devices for use with the HVS. These monitoring devices complement the HVS and provide users with an additional advantage of having available for use technology, data processing, and analysis procedures that have been thoroughly tested over the years.

5. Selection of the HVS provides ADOT the ability to coordinate and partner with our neighboring State, California, which runs one of the most successful APT programs. Also, it will be possible for ADOT to form a consortium with other western states (e.g., New Mexico, Nevada, Utah and possibly Utah) for a regional APT program.

6. By the end of 2000 it is anticipated that there will be a total of five HVSs in the U.S. (i.e., two at CAL/APT, and one each at CRREL, WES, and Florida DOT) in addition to the two owned by CSIR of South Africa. This provides a unique opportunity for the transfer of useful technology from the previous APT programs to a newly established AZAPT program.

7. Based on the recent reported experiences of agencies that have purchased HVSs, CSIR offers considerable transfer of technology and assistance to users of the device. Also, Dynatest Consultants Inc. of Ojai California, which markets the HVS in the

U.S. on behalf of CSIR, has a strong reputation in the area of pavement testing equipment and can be relied upon to provide excellent local support if required.

The material presented elsewhere in this report provides additional detailed information to support the recommendation of an HVS for use in an AZAPT program.

RECOMMENDATIONS FOR ESTABLISHING AN AZAPT PROGRAM

Several feasible alternatives for establishing an AZAPT program were presented in chapter 4. The merits and disadvantages of each feasible alternative were also outlined. Following a careful evaluation of these feasible alternatives and the resources available, the research team recommends a step-by-step approach for establishing an AZAPT program that incorporates the best elements of the feasible alternatives described in chapter 4. This approach takes advantage of Arizona's unique circumstance to achieve a goal that would otherwise be difficult to attain.

Step 1: Exploratory Activities

A major objective of this first step will be to determine the primary partners for the AZPT program, form a working group of core supporters, and establish the direction for the program. From this study it is evident that two kinds of APT programs are suitable to meet the research needs of a state DOT like ADOT. The first type is typically an APT research program run by a national transportation research organization, and that may occasionally cater for an individual need of a DOT. Examples of such APT programs include those run by CSIR of South Africa, ARRB TR of Australia, WES, CRREL, and the FHWA PTF. It is unlikely that such an approach will be effective for tackling the anticipated research needs of Arizona outlined previously.

Most of the other APT programs encountered in this study involve a local partnership between the DOT and a local university that manages the day-to-day operations (e.g., CALTRANS, INDOT-Purdue, LTRC, LINTRACK). In fact, a majority of the APT programs in the U.S. are structured similarly, with state DOTs forming partnerships with local universities. Details of the many advantages offered by such a partnership were provided in chapter 4. Thus, an AZAPT program with ADOT and the three State universities as the basic partners is recommended. During step 1 it is recommended that ADOT explore the potential for including other partners in the core group.

As part of step 1 an early meeting between ADOT and a small group of representatives of the potential partners for the APT program is recommended. During this meeting ADOT can present the preliminary strategic research plan to the potential partners and determine the viability of establishing the APT program proposed in the plan. The preliminary research goals for the APT program included in this report will be discussed and comments solicited from the participants. The comments obtained from this meeting will be incorporated into the report to develop a preliminary strategic research plan for the AZAPT.

Step 2: Workshop on AZAPT

The information obtained from these initial activities will quickly make it obvious whether the approach recommended for establishing an AZAPT program will work. If the results are positive, a workshop will be held to explore further the potential for establishing an AZAPT program. The objective of the workshop will be to flesh out in detail the strategic research plan for the AZAPT program. Potential participants to the workshop recommended include representatives from the following:

- State universities in Arizona.
- Neighboring state DOTs (e.g., New Mexico, Nevada, Utah, and Colorado).
- Other federal, state, county, city, and other local transportation-related agencies (e.g., FHWA, Forest Service, Maricopa Association of Governments, City of Phoenix).
- Highway contractors.
- Materials suppliers.
- Other private industry

- Industry or trade organizations (e.g., NAPA, ACPA) and consulting firms

The preliminary strategic research plan for establishing the AZAPT program will be presented to the participants at the workshop to solicit further comments. This preliminary strategic research plan should include final details of the pavement evaluation, testing, and research goals of the proposed program. If possible the strategic research plan should be provided to the participants prior to the workshop so that comprehensive comments can be solicited. Following the workshop, it should be clear if the support exist for the establishment of an AZAPT program. If so, the desirable partnership arrangement will be formalized and an advisory group established to oversee implementation of the APT program. Also, the strategic research plan will be finalized.

Step 3: Soliciting Funding

Following the workshop, the advisory group will direct its efforts towards obtaining the necessary funds for establishing the program. Details of funding scenarios and mechanisms, resource needs, logistics, and costs are given in chapter 4. The availability of funding will determine the partnership arrangements that will be considered. The information obtained from the workshop in Step 2 will give an indication of where to direct the efforts to solicit funds for the APT program.

Obviously an AZAPT program headquartered in Phoenix with field test sites at other locations in the State will be most beneficial. Therefore, the first objective in Step 3 will be to solicit funds for an AZAPT program solely supported by an Arizona-based consortium. The second alternative will be to obtain funds from a pool of States to form a potential regional consortium. The last and least desirable alternative will be the case where only a limited amount of funds is obtained for collaborative efforts with the CAL/APT program.

Table 5.1 shows the estimated costs for the first three years of an AZAPT program based on the resource needs and cost information obtained previously. For the purpose of this estimate, it is assumed that the cost of materials for construction of test sites will come from regular construction budgets. Thus, even with adjustments made for inflation it is believed that the estimated cost per year for the program (excluding non-recurrent costs incurred during the first year) will be less than $0.5 million. Past experience shows that it is feasible to raise such funds from federal, state, local, and private sources.

Table 5.1. Estimated cost of AZAPT program.

Item	Year 1	Year 2	Year 3
Cost of HVS and related equipment	$ 1.6 million	-	-
Pilot project/initial training of personnel	$60,000	-	-
Operating costs, maintenance, and repair of HVS	$ 120,000	$150,000	$150,000
Salaries:			
APT Manager @ $80k/yr	$40,000	$40,000	$40,000
Engineering Analyst @ $60k/yr	$30,000	$30,000	$30,000
Senior Technician @ $40k/yr	$40,000	$40,000	$40,000
Part-time support	$20,000	$20,000	$20,000
Contingencies	$30,000	$30,000	$30,000
Total	$1,940,000	$420,000	$420,000

Step 4: Pilot Project

If there is a strong indication following the workshop that an AZAPT program is eminent, the research team strongly recommends the conduct of a pilot project. It will provide ADOT an opportunity to assess what it is getting into and give prospective AZAPT personnel a similar opportunity to become familiar with the APT equipment. A pilot project conducted in collaboration with the CAL/APT program or with CSIR of South Africa is strongly recommended. Preferably arrangements should be made for the pilot project to be conducted in Arizona; however, it that is not possible a pilot project at the CAL/APT or CSIR facility is still recommended. The pilot project should be completed before the start of Step 5.

Step 5: Establish AZAPT Program

The final step will involve establishing the AZAPT program once funding is obtained. Step 5 will be conducted only after the completion of the pilot project in step 4. If adequate funding is obtained to start an AZAPT program that is funded through an Arizona-based consortium or a consortium of neighboring State DOTs, the activities under in Step 5 will be similar. Those activities will be comprised of the following basic subtasks:

- Making arrangements to purchase and take delivery of the APT equipment.
- Preparation of the APT site.
- Training of project personnel
- Preparations to proceed with execution of the approved research plan.

STRATEGY FOR PAVEMENT RESEARCH

An essential element of any successful APT program is a good strategic plan that provides a roadmap for the research work being conducted. Because APT has the potential to be used to solve many pavement problems, without a roadmap to provide guidance there may be a tendency to conduct work that in the end does not address any specific objectives. Keeping an up-to-date strategic plan will compel the agency to conduct research in a structured manner that ultimately leads to comprehensive answers to real-life problems.

With that in mind a key objective of Phase II of this study should be to develop a comprehensive strategic plan once the concrete decision has been made to pursue the establishment of an AZAPT program. The details of the research needs in Arizona identified in chapter 2 provide a good foundation to start from. To provide a framework for developing such a comprehensive strategic work plan, Table 5.2 was developed. The table gives details of the strategic research needs, potential research topics that will address these needs, anticipated results, and the potential benefits that can accrue from the pavement research conducted in an AZAPT program. Implementation of an AZAPT

Table 5.2. Framework for strategic research plan.

Strategic Research Needs	Potential Research Topics	Anticipated Results	Expected Benefits
1. Validating and improving current designs.	1. Evaluating the State's experimental field test sections. 2. Effects of changes in traffic loading patterns and configurations on pavements in Arizona. 3. Performance comparisons to quantify improvements in designs. 4. Evaluating innovative construction practices.	1. Progressive reports on the performance of field sections. 2. Recommendations for legislation on traffic loading restrictions. 3. Improved technology to accommodate heavy vehicles. 4. Recommendations of new construction practices for improved performance. 5. Improved inputs for pavement design procedures.	1. Improved assessment of standard and non-standard designs. 2. Cost-effective and timely testing of innovative designs and practices. 3. Reduced life cycle costs.
2. Evaluating new materials and mixes for pavements.	1. Field evaluation of performance of Superpave mixes. 2. Evaluation of in-service performance of innovative pavement materials and mixes.	1. Recommendations for improving Superpave mix design. 2. Improved characterization parameters (e.g., equivalencies) for Superpave mixes. 3. Development of new materials and mixes with improved performance characteristics.	1. Elimination of potential costly failures of pavements constructed with Superpave mixes. 2. Timely application of innovative materials and mixes. 3. More effective use of innovative pavement materials and mixes.
3. Effectiveness of maintenance and rehabilitation practices and strategies.	1. Field evaluation of new maintenance practices. 2. Field evaluation of new rehabilitation practices. 3. Procedure for selecting the best M&R strategies.	1. Improved materials for maintenance and rehabilitation. 2. Improved M&R construction practices. 3. Recommended strategies for maintenance of flexible pavements. 4. Recommended strategies for rehabilitation of pavements.	1. Reduced life cycle costs. 2. Improved pavement performance in Arizona. 3. Reduced delay and user costs on Arizona's highways. 4. Improved confidence in M&R planning.

Table 5.2. Framework for strategic research plan.

Strategic Research Needs	Potential Research Topics	Anticipated Results	Expected Benefits
4. Developing performance-related specifications.	1. Identifying significant construction quality evaluation parameters. 2. Calibration of State PRS models.	1. Improved input into construction practices. 2. Pay factors for pavement construction in Arizona. 3. QA/QC guidelines for pavement construction.	1. Improved quality of newly constructed pavements. 2. Rational pay factors for pavements. 3. Improve understanding of construction factors.
5. Developing guidelines for use of marginal materials.	1. Quantitative evaluation of marginal, waste, and other by-products. 2. Design recommendations for marginal materials used in pavements.	1. Specifications for marginal materials appropriate for use as replacements for conventional materials. 2. Guidelines for selecting appropriate binder type and proportion for marginal materials.	1. Improved assessment of marginal materials. 2. Increased availability of materials for pavement construction and repair. 3. Reduction in the cost of materials for roadway construction.
6. Improving pavement design methods for new and rehabilitated Pavements.	1. Implementing a State mechanistic-based pavement design procedure. 2. Developing improved pavement analysis procedures. 3. Identifying design features beneficial to long-term performance.	1. Improved new pavement design procedures for Arizona. 2. Recommended design features for extending pavement life. 3. Improved overlay design procedures for Arizona.	1. Improved pavement performance. 2. Improved confidence in design recommendations. 3. Better prediction of resource requirements for managing pavements.
7. Improving performance prediction and pavement management techniques.	1. Validation and calibration of pavement performance models. 2. Validation/calibration of response models. 3. Validation/calibration of backcalculation procedures. 4. Establishing limiting criteria for M&R.	1. Improved mechanistic-based performance prediction models for inclusion in Quantum PMS. 2. Improved backcalculation procedures for pavements. 3. Optimal timing of M&R options.	1. Improved pavement performance. 2. Improved allocation of resources for maintaining pavement network at high level of service.

program based on this plan will greatly enhance the timeliness of pavement research in the State. Some of the specific advantages that the plan will offer include the following:

1. Ability to use it as a planning tool during formulation of ADOT's annual pavement research program.
2. Coordination between successive annual pavement research programs so that both specific short-term and long-term goals identified in the overall plan will be met.
3. Provision of a frame of reference that the different divisions within ADOT can use as a check on whether their needs are being addressed, and also to learn about how their needs/activities fit into the overall scheme of things.
4. A means for defining the critical research needs of the state so that the appropriate funding and level of effort can be directed to meet those needs and thereby maximize the return on the state's investment in pavements.
5. Facilitating the conduct of pavement research using the APT facility in accordance with an established timetable and in congruence with overall goals.
6. Promotion of the movement of research results obtained into practice by providing advance knowledge of the results expected and making provisions for the appropriate implementation of results.

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

This study was conducted to determine the reasonableness of using APT as a means for conducting pavement research in Arizona in a timely manner. It involved an identification of the research needs of Arizona and an assessment of the effectiveness of using APT to address those needs. Based on a conclusion of the reasonableness of using APT in pavement research, the study investigated the feasibility of establishing an AZAPT program in Arizona. This chapter provides the conclusions and recommendations of the research.

RESEARCH NEEDS

As a progressive agency ADOT promotes extensive research to provide solutions to the myriad of pavement problems that are faced in the State. One of the primary objectives of this study was to identify the pavement research needs anticipated in Arizona during the next several years. The study identified research needs in the following seven broad categories that are described in detail in chapter 2:

- Validating and improving current pavement designs.
- Evaluating new materials and mixes for pavements.
- Evaluating effectiveness of maintenance and rehabilitation practices and strategies.
- Developing performance-related specifications.
- Developing guidelines for use of marginal, waste, and other by-product materials.
- Improving pavement design methods for new and rehabilitated pavements.
- Improving performance prediction and pavement management techniques.

Because of changing priorities that could bring about a different set of problems and new advances such as new products, materials, or techniques that could make current research needs obsolete, it is recognized that this list is not exclusive.

EFFECTIVENESS OF APT FOR PAVEMENT RESEARCH

To find solutions to the research needs identified, ADOT currently uses traditional research methods that often depend on researchers evaluating in-service pavement by observing their performance over long periods. Recent developments in accelerated pavement testing and the proximity of ADOT to the WesTrack and CAL/APT projects, brought about the need to investigate in this study the reasonableness and effectiveness of using APT to address some of the research needs identified.

From a comprehensive literature review and responses to a questionnaire survey the study found many examples of the effective use of APT to address research needs. The results indicate that major strides have been made in the past decade on the successful use of APT for pavement research and it provides an effective and economical means for solving many pavement problems in a timely manner. Also, there are currently several agencies with experience in APT and vast amounts of knowledge, data, and technology are available for future users to take advantage.

Examples of the successful and effective use of APT for evaluating the effect of new materials, design features, and construction practices on performance in a relatively short time were found in South Africa, France, the Netherlands and the United States. The results from such APT tests and from the evaluation of potentially innovative techniques have been used to improve pavement analysis and design. Also, the study found that in Australia, France, and South Africa, APT has been used to compare the effectiveness of different maintenance and rehabilitation strategies, and, subsequently, to develop recommendations that have been implemented in practice.

Evidence was uncovered in South Africa and Australia of the effective use of APT to develop specifications and mix designs for marginal materials that were incorporated in pavements to reduce life-cycle costs. The effective use of APT in efforts to develop performance-related specification is also found from the CAL/APT program and the WesTrack project. In general this study provides evidence that significant successes can be achieved with APT to improve pavement performance and management, and that this is an opportune time for a DOT (or group of DOTs) to start an APT program.

FEASIBILITY OF AN AZAPT PROGRAM

Based on these initial conclusions an investigation was conducted to determine the feasibility of using APT to address Arizona's pavement research needs. The study concludes that the relatively high initial price for establishing and operating a full-scale APT program for pavement research can be a major obstacle. However, taking into consideration the benefits that will quickly accrue for an APT program should alleviate this. An evaluation of the available alternatives based on criteria established during this research, identified a mobile, linear tracking device as the most suitable equipment type for Arizona's needs. The equipment types in this category include the HVS, the ALF, and the TxMLS.

Following a critical examination of these three types of devices, both the HVS and ALF emerged as the two units suitable for establishing an AZAPT program. A further examination of their suitability for an AZAPT program, lead to the conclusion that the HVS is a better machine overall because of several factors. Detailed information on the factors that were examined including costs, resource needs, logistics, partnership, and funding scenarios and mechanisms are contained in this report.

IMPLEMENTING AN AZAPT PROGRAM

From the results obtained a strategic plan was developed for establishing an AZAPT program. The plan outlines a step-by-step process for setting up an AZAPT program and includes specific recommendations for establishing a partnership between ADOT and the three State universities as a means of obtaining funding to support the program. Other partners identified for inclusion in the program to provide additional support include other State DOTs; federal, state, county, city, and other local transportation-related agencies (e.g., FHWA, Forest Service, Maricopa Association of Governments, City of Phoenix); highway contractors; materials suppliers; and other private industry. Finally, the plan provides estimates of the cost for the first three years of an AZAPT program and a framework of a strategic pavement research plan for the program.

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APPENDIX A: QUESTIONNAIRE ON ACCELERATED PAVEMENT TESTING

Questionnaire on Accelerated Pavement Testing

The Arizona Department of Transportation (ADOT) is evaluating the potential for using Accelerated Pavement Testing (APT) in its pavement research program. Your answers to the following questions will help in this endeavor. Please feel free to attach additional sheets with additional information where necessary.

Does your agency own/use an APT facility? Yes ______ No _______

If yes, please complete the following questionnaire. If your agency owns/uses more than one facility, please complete one questionnaire for each facility. If your agency does not own/use an APT facility, please provide any comments or publications that could be of assistance to ADOT in the evaluation.

1. **What is the name of your APT facility?** ________________________________

2. **How would you classify your APT facility? Please check one.**
   a. _____Full-scale test track loaded with trucks of known loads.
   b. _____Full-scale fixed mechanical loading device, e.g., ALF, LCPC
   c. _____Full-scale mobile mechanical loading device, e.g., Heavy Vehicle Simulator (HVS), Mobile Load Simulator (MLS)
   d. _____Small-scale laboratory device
   e. _____Other

3. **If you selected 2a,**
   a. What is the shape of the test track? ________________________________
   b. How many lanes are there in the test track? ____________________________
   c. What are the dimensions of the test track? If available, please provide sketch of layout. ____
      ____
      ____
   d. What are the load magnitudes applied by the trucks? ____________________
   e. What is the average speed of the trucks? ____________________________
   f. What is the approximate cost of the test track? If available, please attach information on cost details. ____________________________________
   g. What is the approximate cost of the loaded trucks? ______________________
   h. What is the approximate operation cost per day? If available, please attach information on cost details. ____________________________________
   i. Source of funds. ____

If you selected 2b or 2c,

a. Is the loading device linear or circular? ______________________________
b. Is the load applied in one direction or two? ____________________________
c. What are the approximate dimensions of the loading device? If available, please provide sketches, drawings, photographs, etc.

d. How many axles and wheels? ____
e. What is the load on each axle/wheel? _________________________________
f. What is the average speed of operation? _______________________________
g. What is the approximate cost of the device? If available, please attach information on cost details, e.g., initial cost, maintenance service contract, warranty.

____
____
____
____
____

h. What is the approximate operational cost per day? If available, please attach cost details. ____
____
____
____
____

If you selected 2d or 2e,

a. Describe the device in a few sentences:

____
____
____
____
____
____
____
____
____
____

b. Is the load applied in one direction or two? ____________________________

c. What are the approximate dimensions of the device? If available please provide sketches, drawings, photographs, etc.

d. How many axles and wheels, if applicable? ______________________________
e. What is the load on each axle or wheel, if applicable? ______________________
f. What is the average speed? ____
g. Is there any temperature control? ____
h. What are the approximate dimensions of the pavement section/model?
____
____
____
____
____
i. What is the approximate cost of the device? ______________________________
j. What is the approximate operational cost of the device per test/day? __________

4. List the objectives of some research projects in which your APT facility was used:
   a.
   b.
   c.
   d.
   e.
   f.

5. List the main advantages of your APT facility:
   a.
   b.
   c.
   d.
   e.
   f.

6. List the main weaknesses of your APT facility:
   a.
   b.
   c.
   d.
   e.
   f.

7. Do you have a strategic plan for use of your APT facility? If so, please provide a copy or a short summary of the plan.

8. If you do not have a current APT facility, what facility would you select in order to maximize the benefit to you agency? Comment on your future plans, if any, for an APT program and your agency's interest in regional partnerships.

9. Please provide any comments or recommendations that could be helpful to the subject. Attach additional sheets if needed.

10. Please enclose any photos and/or brochures of your APT facility and any publications on completed or ongoing research conducted with the facility. A list of the publications will be adequate it they can be obtained through the usual channels, i.e., if published.

Name:
Title:
Agency:
Phone:
Fax:
E-mail:

Please e-mail, fax or mail the completed questionnaire to Dr. Emmanuel Owusu-Antwi, Department of Civil and Environmental Engineering, Arizona State University, P.O. Box 875306, Tempe, Arizona, 85287-5306, e-mail: eoa@asu.edu, phone: (480) 965-0199, fax (480) 965-0557. Your assistance in completing this questionnaire is greatly appreciated.

APPENDIX B: RESPONSES TO QUESTIONNAIRE ON ACCELERATED PAVEMENT TESTING

Category	Agency Name	Name of APT Facility	Own/Use APT	Shape	No. of Lanes	Dimensions	Load	Avg. Speed	Cost of test track/device	Cost of loaded trucks
Full-scale test tracks with loaded trucks	Public Works Research Institute, Japan	Pavement Test Field	Yes	Looks like a cross-section of an egg	One	870 m & 628 m	6 to 16 ton axle load	30 Km/h	1000 million Yen(approx. 10 million USD)	100 million Yen(approx. 1 million USD)
Full-scale test tracks with loaded trucks	NCAT	NCAT Oval Test Track	Yes (An Oval test track to be completed in approximately I year i.e. Fall 1999)	Oval	1 may be 2	Appro. 1.75 miles total	Probably 20,000 lbs per axle	45 mph	Appro. $4,000,000	This will be done by contract
Full-scale test tracks with loaded trucks	Virginia Tech.	Smart Road	Yes	1.6 miles (2 lanes) with turns at the ends	Two lanes	1.6 miles (2 lanes). It is part of a 6 mile 2 direction and two lanes in each direction.	Varies 8-32 k/axle	15-65 mph	It will be part of an interstate HY (1.6 miles - approx. $22 M)	
Full-scale test tracks with loaded trucks	MnDoT	Mn/Road	Yes	Loop - LVR	Two lanes(inside 80K, outside 102K 5 axle semi)	3.5 miles of I-94	80 K - 102 K	30 - 40 MPH (depends on gravel sections)	$170,000 equipment 1 Full Time Driver 1 Full time Laborer / Backup	
Full-scale test tracks with loaded trucks	The Circle Test Track Vuis - CESTY (KDS)	Circle Test Track Vuis - CESTY, Ltd. Abbr. KSD	Yes	Circle	6	Radius= 16m (in axis) Width of track= 6m	80 - 130 kN axle load	30 km/hr	40 million Sk	
Full-scale test tracks with loaded trucks	WesTrack	Westrack	Yes	Oval	2	The tangent sections are 10.4 m (34 ft) wide consisting of two 3.7 m (12 ft) lanes with a 1.2 m (4 ft) HMA shoulder outside and a1.8 m (6 ft) gravel shoulder inside	10.48 ESAL per truck pass	64 km/hr (40 mi/hr)		
Full-scale test tracks with loaded trucks	Ohio University	Ohio SHRP test Pavement	Yes Ohio SHRP Test Pavement owned by ODOT	Straight section of in-service pavement	4	3.5m long	Real traffic, controlled vehicles	Highway speed or slower as required	$ 15,000,000	ODOT dump trucks for controlled tests

RESPONSES TO QUESTIONNAIRE ON ACCELERATED PAVEMENT TESTING

	Agency Name	Name of APT Facility	Own/Use APT	Shape	No. of Lanes	Dimensions	Load	Avg. Speed	Cost of test track/device	Cost of loaded trucks
Fixed, linear mechanical loading devices	Delft University of Technology, Road and RailRoad Laboratory, Netherlands	Lintrack	Yes	Linear		Overall Length = 22m, Wheel path length = 12m, Overeall Width = 6m and Wheel path width upto 2m		Max. Speed = 20 km/h (between acceleration and deceleration) Programmable between 0 and 20 km/h	Initial Cost: NLG 1.8 million (approx. USD 0.9 mio), Maintenance Cost: NLG 120,000/year (approx. USD 60,000/year)	
	Ohio University	1. Accelerated Pavement Loading Facility 2. Ohio SHRP test Pavement	Yes APLF owned byOhio State Univ.	Linear	4	Test pit 45'long * 38'wide * 8' deep	Real traffic, controlled vehicles	5 mph	$1,300,000 for entire facility	ODOT dump trucks for controlled tests
	Technical University of Denmark, Denmark	Danish Road Testing Machine (RTM)	Yes	Linear		Danish Road Testing Machine, RTM2 - 2.5 m * 2.0 m Protected Strain Gauge - 9.5 mm wide * 4.5 mm thick		20 - 30 Km/h		
	Kansas State University	Kansas Accelerated Testing Lab	Yes	Linear		Appro. 48 - ft long (total)		5 mph, 7 mph on specimen	Device was custom made. Costs were mixed up with other expenses such as building construction, personnel, equipment, heating and cooling devices. Best estimate: $250,000 for machine and frame	
	Laboratoire des Voies de Circulation - Laboratory of traffic facilities Ecole Polytechnique Fédérale de Lausanne - Swiss Federal Institute of Technology	Heavy Pavement Rutting Tester	Yes	Linear		19 x 5 x 2 (depth) max 4 to 5 different sections		12 km/h	today 2 Million of US$ (included 0.5 Million of US$ only for the loading device)	
loading devices	INDOT	Indiana Department of Transportation Accelerated Pavement Testing	Yes			20 ft * 20 ft * 6 ft		5 MPH - 8 MPH	$ 150,000 (1991)	

	Agency Name	Name of APT Facility	Own/Use APT	Shape	No. of Lanes	Dimensions	Load	Avg. Speed	Cost of test track/device	Cost of loaded trucks
Fixed, linear mechanical	University of Nottingham	Nottingham Pavement Test Facility	Yes			8m long * 1.1m high * 0.8m wide (pavement 2.4m wide)		Variable, usually 8km/hr	£ 60,000 (approx. $98,400)	
Mobile, linear mechanical loading devices	Research Institute of Highway, Ministry of Communications, P. R. China	Accelerated Loading Facility	Yes	Linear		Long*Wide*High : 27m*3.3m*4.2m (for Transportation) 27m*4.5m*5.7m (for Operation)		20 km/h	The approximate cost per year is 300,000 RMB¥ ($36,000)	
Mobile, linear mechanical loading devices	FHWA	Accelerated Loading Facility	Yes	Linear		94' L * 12' W * 20' H		10.3 mph - 10.6 mph (Approx. 8,400 load passes/day)	ALF 1 - $1,000,000 (1985) ALF 2 - $1,500,000 (1993)	
Mobile, linear mechanical loading devices	LTRC	LTRC's Pavement Research Facility	Yes	Linear		The ALF is approximately 100' long and 8' wide. Total loading length is approximately 42'		10.5 mph	Approx. 2 million dollars	
Mobile, linear mechanical loading devices	TxDOT	Texas Mobile Load Simulator	Yes	Circular in vertical direction		Overall Width(W) 12 ft. 6 in., Overall Length(L) 86 ft. 5 in., Overall height(H) 22 ft. 6 in.		12 - 14 Mph; 6000 Axle reps/hr	Initial cost approx. $ 3.2 M Annual operating cost appro. $ 1 M	
	CSIR, Pretoria, South Africa	Heavy Vehicle Simulator	Yes	Linear				Approx: 12 Km/hr	Approx. US $ 1.2 million	

RESPONSES TO QUESTIONNAIRE ON ACCELERATED PAVEMENT TESTING

	Agency Name	Name of APT Facility	Own/Use APT	Shape	No. of Lanes	Dimensions	Load	Avg. Speed	Cost of test track/device	Cost of loaded trucks
Mobile, linear mechanical loading devices	Univ. of California, Berkeley	Caltrans Accelerated Pavement testing (CAL/APT)	Yes	Linear		3 - 7 m wide		5 mph	Initial Cost + Warranty (used) - $750 k each	
	Technical Research Center (VTT)	HVS - NORDIC	Yes	Linear		Dimensions 23*3.7*4.2 m Main test area : full water table control temperature control, frost and thaw tests possible (done)		12 km/h	Initial Cost 1.7 M USD	
	ARRB Transport Research Ltd., Australia	Accelerated Loading Facility	Yes	Linear		Over all Length = 26.3 m Over all Width = 4 m (operating), 3.2 m (transport) Over all Height = 5.7 m (operating), 4.4 m (transport)		20 Km/h (9 seconds cycle time)	The cost of manufacturing an ALF now would be of the order of US$1.5-2.0 million.	
Fixed, circular mechanical loading devices	IVT - ETH, Honggerberg, CH-8093 Zurich	Rundlauf ETHZ Switzerland Circular Pavement Test Track, Swiss Federal Institute of Technology, (SFIT) Zurich	Yes	Circular		Ø 32m		< 80 Km/h		
	Saskatchewan Department of Highways and Transportation, Saskatchewan		Yes	Circular		Circular test track sub-divided into 5 sectors Track radius is 6.0m on C/L 3.65m track width Wheel can wander over a 1.2m width 37.7m length on C/L 1.5m deep		6.5 m/s (max = 8.0 m/s)		

Category	Agency Name	Name of APT Facility	Own/Use APT	Shape	No. of Lanes	Dimensions	Load	Avg. Speed	Cost of test track/device	Cost of loaded trucks
Fixed, circular mechanical loading devices	Institute of Engineering, UNAM, Mexico	Pista Circular del Instituto de Ingenieria, UNAM / Circular Test Track of the Institute of Engineering, UNAM	Yes	Circular		The three-arm loading device (with a total weigh of 15 metric tons) has a diameter of 10 m. On each arm there is a heavy duty crane motor of 40 HP. The loading device is constructed inside a heavy reinforced concrete pit, 13 m in diameter.		Avg. Speed is 10 - 12 km/hr (can be increased upto 40 km/hr)	Approx. US $ 1 million (with very low costs of maintenance after 27 years of service)	
Fixed, circular mechanical loading devices	Centro de Estudios y Experimentación de Obras Públicas (CEDEX)		Yes	Combined: Linear+Circular				40 km/h (0-60 km/h)	Initial cost: 1.5×10^6 dollars (infrastructure) + 2.5×10^6 USA dollars (vehicles) + 1.5×10^6 USA dollars (data adquisition system) Maintenance service contract : 250.000 USA dollars	
Fixed, circular mechanical loading devices	LCPC - France	LCPC APT Facility	Yes	Circular		Inner radius = 15m Outer radius = 20m		From 30 - 100 km/h (current 70 km/h)	Initial cost : atleast 5,000,000 USD Each year : atleast 100,000 USD	
Fixed, circular mechanical loading devices	Univ. of Washington		No							
Other	BAST	Pulsating Load Applicator	Yes	Model - Construction M 1:1 Linear	One in each test area		Upto ten tons a wheel (simulated by impulse)	Approx. 60 Km/h	200,000 DM (approx. $112,000, 20 Years ago)	

RESPONSES TO QUESTIONNAIRE ON ACCELERATED PAVEMENT TESTING

	Agency Name	Operational costs	Source of funds	Load direction (1 or 2)	No. of axles and wheels	Load on each axle/wheel	Device	Temperature Control
Full-scale test tracks with loaded trucks	Public Works Research Institute, Japan	100,000 Yen/day (approx. $1000/day including measurements)	Ministry of Construction, Govt. of Japan					
	NCAT	$2,150,440 (Year1) $1,599,986 (Year2) $214,438 (Year3)	State DoTs					
	Virginia Tech.		VDOT / FHWA and Industry. A lot of ITS work will be conducted at the road					
	MnDoT		Mn/DoT, FHWA, Minnesota Cities & Counties	One direction (Westbound I-94)			Mainline I-94 Westbound Traffic includes - 23 Test Cells (Asphalt & PCC), 6 Ultra thin Whitetopping sections, 2 Superpave sections (Note: 11 Test cells are SHRP/LTPP test sections)	No
	The Circle Test Track Vuis - CESTY (KDS)	Building roads and their demolition 600 m^2=2.5 million Sk	Private or State					
	WesTrack		FHWA					
Full-scale test tracks with loaded trucks	Ohio University		FHWA/ODOT	Either 1 or 2	One wheel - either dual or super single tires	5,000 - 30,000lbs.		

RESPONSES TO QUESTIONNAIRE ON ACCELERATED PAVEMENT TESTING

	Agency Name	Operational costs	Source of funds	Load direction (1 or 2)	No. of axles and wheels	Load on each axle/wheel	Device	Temperature Control
Fixed, linear mechanical loading devices	Delft University of Technology, Road and RailRoad Laboratory, Netherlands	Cost per month: two operators/measurement people NLG 15,000, data analyst NLG 10,000, amortization NLG 15,000 Total costs (excluding power) NLG 50,000/month		Generally in two directions, but the facility is capable of one-directional traffic	One truck-size wheel (single, super single or dual)	15 to 100 kN		Yes, Watlow infrared heaters (50 kW max. output) to heat 12*3 sq.m pavement upto 30C above ambient)
	Ohio University		FHWA/ODOT	Either 1 or 2	One wheel - either dual or super single tires	5,000 - 30,000lbs.		
	Technical University of Denmark, Denmark	Yearly costs at full testing capacity is 300,000 - 400,000 USD, half of which would be data interpretation and reporting		Two	One axle, one or two wheels	20 KN - 65 KN		
	Kansas State University	Load Application : ($33/hr) or $22+overhead Heating by radiation : $110/day + overhead Cooling/heating with glycol $180/day + overhead		One or Two	1 or 2 axles - Duals	Maximum total load 40,000 lbs		
	Laboratoire des Voies de Circulation - Laboratory of traffic facilities Ecole Polytechnique Fédérale de Lausanne - Swiss Federal Institute of Technology	500 US$		Two	one axle with 2 double or single wheels	20 to 130 kN on the axle		
loading devices	INDOT	$ 13,000 per Year		Can be applied in one or two directions	Loads can be applied with a dual wheel or a supersingle half axle assembly		The APT facility is housed in a 2,000 sq.ft. environmentally-controlled building comprising a test pit, loading mechanism, and control and monitoring equipment. A unique loading mechanism applies and maintains a constant force of upto 20,000 lbs on the wheel assembly. With modifications this half-axle loading can be increased to 40,000 lbs, applied statically or as a programmed dynamic load function	Yes

	Agency Name	Operational costs	Source of funds	Load direction (1 or 2)	No. of axles and wheels	Load on each axle/wheel	Device	Temperature Control
Fixed, linear mechanical	University of Nottingham	£100/day ($164/day)		Optional, usually two way	One	Variable, usually 12 KN (15 KN max.)	A 1/3 to 1/2 scale testing facility based on load, but capable of testing realistic pavement structures in a controlled laboratory environment. The system comprises a wheel loading carriage running on a pavement section in a temperature controlled laboratory. The carriage reacts against two longitudinal frames which sit on rails at each end of the pavement. This allows lateral travessing at the wheel while it is running.	Yes
Mobile, linear mechanical loading devices	Research Institute of Highway, Ministry of Communications, P. R. China	The approximate cost per day is 1,000 RMB¥ ($120)		One direction	Half axle and dual wheels	40~100 KN increased in 10 KN for one step		
	FHWA	$400 / day - labor w/ 2 operators $55 /day - parts & maintenance $100 /day - electrical power (for heaters) $555 / day - Total Cost / Day		One	One	10,000 lbs - 20,000 lbs		
	LTRC	$1,000 / day		One direction	1 axle, 2 wheels	Varies 9,750 # to 21,500 #	The device is the Australian designed Accelerated Loading Facility. It Operates 24 hours/day and shuts down automatically approximately every 3 days for routine maintenance and performance testing methods include: 1) profile measurements 2) crack measurements 3) FWD and Dynaflect measurements and 4) various instrumentation data collection. The device moves horizontally to simulate truck wander.	No
	TxDOT			One	6 bogies; 12 axles; 48 wheels	Set to std. 18 Kip loading; can exceed by 25%	Prior to buiding the TxMLS a 1/10 Scale Model was built. There are 1/3 Scale Models now available. TTI has recently purchased a 1/3 Scale Model that will be evaluated in August, 1998	
	CSIR, Pretoria, South Africa	In South Africa : Approx. R 8,000 - currently about US $ 1,200		Can be either, but usually bi-directional for productivity	1/2 axle; dual or single wheel configuration	Upto 100 KN / wheel configuration		

RESPONSES TO QUESTIONNAIRE ON ACCELERATED PAVEMENT TESTING

	Agency Name	Operational costs	Source of funds	Load direction (1 or 2)	No. of axles and wheels	Load on each axle/wheel	Device	Temperature Control
Mobile, linear mechanical loading devices	Univ. of California, Berkeley	Op. Cost in field - $100 k/month at RFS - $80 k/month (excluding analysis beyond 1st level)		One or Two directions	Half axle; any tire configuration i.e., dual tires, super single tire, aircraft tire	20 - 150 kN/axle; upto 200 kN for static test		
	Technical Research Center (VTT)			Both	One	30 - 110 kN		
	ARRB Transport Research Ltd., Australia	A$12,000 (say US$ $8,000) per month to cover ALF maintenance, spare parts, power, etc.		One	One axle with either one set of dual wheels or a single wheel	4 - 8 tonnes in One ton increments		
Fixed, circular mechanical loading devices	IVT - ETH, Honggerberg, CH-8093 Zurich	~ 400 CHF/day		One	3	< 80 metric tonnes		
	Saskatchewan Department of Highways and Transportation, Saskatchewan			One	One axle - Two wheels	max = 60 kN min = 40 kN		

RESPONSES TO QUESTIONNAIRE ON ACCELERATED PAVEMENT TESTING

	Agency Name	Operational costs	Source of funds	Load direction (1 or 2)	No. of axles and wheels	Load on each axle/wheel	Device	Temperature Control
Fixed, circular mechanical loading devices	Institute of Engineering, UNAM, Mexico	The operational cost per day includes the salary of technicians and the cost of electricity, which is not very high		One	3 axles with double wheels	Load on the outer two wheels is 5 metric ton (10 to single axle load)		
	Centro de Estudios y Experimentación de Obras Públicas (CEDEX)	2,000 USA dollars		One	2 vehicles ; 1-2 axle/vehicle; 1-2 wheels/axle	usually 6,5 t (5.5-7.5 is possible)		
	LCPC - France	Layers construction : from 50,000 to 150,000 USD Per day : about 1500 USD plus measurements and lab studies (depending on the test program) + final report		One	Upto 4	From 4 - 15 t depending on the axle		
	Univ. of Washington							
Other	BAST			Two			The loading apparatus is so designed that as far as a repeated load application is concerned, it is only suitable for flexible pavements.This is based on the load application mechanism - a hydraulically driven pressure cylinder - with which a wheel pass is simulated only on an asphalt pavement using the rheological characteristics of asphalt. The loading case pulsating stress and alternaing shearing effected is brought about by the PLA in such a way that the PLA during load application moves progressively in short increments i the direction of travel in a load application track.	

RESPONSES TO QUESTIONNAIRE ON ACCELERATED PAVEMENT TESTING

	Agency Name	Dimensions of pavement section/model	Objectives	Advantages
Full-scale test tracks with loaded trucks	Public Works Research Institute, Japan		a. Evaluation of Crack preventing materials b. Evaluation of Interlocking Block Pavement c. Evaluation of Durability of Epoxy asphalt	Simulation of real traffic using actual tracks
	NCAT			
	Virginia Tech.		a. Significant ITS research will be conducted b. Measure pavement response to loading and environmental changes c. Calibration for FWD (measuring during construction) d. Optimize design methods (different layers and thickness) e. Evaluate geosynthetics for crack reduction, reinforcement f. GPR research	a. All weather condition (can apply snow up to 4 in/h or rain up to 3 in/h) and has cut and fill b. 12 different flexible pavement designs and has different slopes c. Use of geosynthetics d. Will be equipped to calibrate radar systems e. Will allow monitoring the drivers and data collected to control center through fiber optics
	MnDoT		1. Verification of Empirical Design Models and development of mechanistically based design methods and vehicle load damage factors. 2. Verification / Improved frost action prediction methodology 3. Influence of AC mixture properties upon performance / distress 4. Influence of unbound granular base/subbase properties, subgrade type upon pavement performance / distress 5. Influence of pavement variability upon reliability-based performance models	a. No. of sensors and monitoring done b. No. of test sections - Real Time/Life Experiment c. Backing by Minnesota & FHWA (funding) d. Located in a cold region e. Large research staff & partners working towards common goals f. People
	The Circle Test Track Vuis - CESTY (KDS)		a. To Verify the suitability of a proposal method from the point of view of its working time b. To judge the asphalt mixtures from the viewpoint of the resistance to permanent deformation c. To verify various ways of thickening the roads (for Austria) d. To verify various kinds of aggregates (crushed, hoisted) e. To verify the aggregates from the slag.	a. The scale of a testing track is 1:1 b. The track built by road building machines c. Loading by a complete axle with 2 duplicated wheels d. Changeable transverse shift of an axle like on a common road e. Constant axle - load, real dynamic effects
	WesTrack		a. Further development of PRS for HMA pavements b. Provide early field verification of the SHRP Superpave HMA mixture design method	a. Realistic loading applied by actual trucks. b. Cost effective driverless technology. c. Strict and thorough QC/QA procedures in place for construction and data collection. d. Well planned and implemented performance data collection activities e. Extensive laboratory materials characterization program
Full-scale test tracks with loaded trucks	Ohio University		Determine dynamic response of typical pavement sections	a. Controlled envi. Condts. b. Full scale con. equip. can be used to build test sections c. Can add moisture to subgrade d. Can test two full lanes of pvmt. e. Can test asphalt and PCC pvmt.

RESPONSES TO QUESTIONNAIRE ON ACCELERATED PAVEMENT TESTING

	Agency Name	Dimensions of pavement section/model	Objectives	Advantages
Fixed, linear mechanical loading devices	Delft University of Technology, Road and RailRoad Laboratory, Netherlands	16 m long, width depending on test purposes (last test sections were 4m wide, which were trafficked with a 1.6 m wide lateral wander)	a. Validation of the pavement design system of the Dutch Ministry of Transport b. Validation of response and performance models c. Identification of distress mechanisms d. Validation of back-calculation procedures e. Modelling of the surface cracking phenomenon f. Development of a 'code of practice' for APT	a. Capability of precise load positioning b. No shearing forces as in circular tracks c. Capability of pavement heating / semi-controlled moisture conditions d. Extensive measurement facilities in/around the test pavements e. Associated with materials laboratory and modelling facilities f. 7 years experience in APT g. Enough space to construct test pavements
	Ohio University		Determine dynamic response of typical pavement sections	a. Controlled envi. Condts. b. Full scale con. equip. can be used to build test sections c. Can add moisture to subgrade d. Can test two full lanes of pvmt. e. Can test asphalt and PCC pvmt.
	Technical University of Denmark, Denmark		a. Verification of response models b. Development of deterioration models (permanent deformation & fatigue) c. Effects of freeze - thaw and temperature d. Effects of water e. Use of waste products f. Steel reinforced sand	a. Durable and reliable instrumentation b. Long experience c. Climate control d. Ground water control
	Kansas State University			
	Laboratoire des Voies de Circulation - Laboratory of traffic facilities Ecole Polytechnique Fédérale de Lausanne - Swiss Federal Institute of Technology		a. Pavement design methods (development and calibration) b. Rutting at high temperature c. Low temperature behavior of structures d. Long term performance of pavement e. New materials as high modulus bituminous layer	a. Complete control of climatic conditions b. Large variation in controlled temperature
loading devices	INDOT	20' * 20' * 3"	a. Validation of Superpave mixtures specifications b. Effect of tire pressure on pavement performance c. Determine minimum crushed aggregate requirement in flexible pavement d. Evvaluate warranty mix performance e. Verification of SHRP mixtures performance	a. Dual wheel or Superwide wheel assembly b. Temperature control c. Uni or bi - direction d. Ability to increase load to 20,000 lbs / 40,000 lbs (9,000 currently) e. Can ably single path or traffic wonder

RESPONSES TO QUESTIONNAIRE ON ACCELERATED PAVEMENT TESTING

	Agency Name	Dimensions of pavement section/model	Objectives	Advantages
Fixed, linear mechanical	University of Nottingham	5m long * 2.4m wide * 1.4m deep. 4m loaded length. Generally a three layer pavement consisting of 1.1m Clay subgrade covered with an unbound material (200mm) and a bituminous upper layer (100mm)	a. Validation of pavement design models (deformation) b. Assessment of fabric, grids and modified mixtures c. Performance of access chambers, bridge deck joints and trench systems. d. Assessment of industrial by-products for road bases e. Development of pavement instrumentation f. Behavior of lean concrete bases.	a. Controlled conditions for testing and construction b. Reasonably quick throughout of pavements c. Very good for testing deformation sensitive materials d. Full pavement instrumentation for stress, strain, temp etc. e. Large enough for installation of standard pavement materials f. Can test structures in series for direct performance comparisions
Mobile, linear mechanical loading devices	Research Institute of Highway, Ministry of Communications, P. R. China		a. Performance evaluation b. Rutting test c. Bearing capability test d. Material development e. Theorization validate f. Long term Pavement Performance	a. Full - Scale b. Movable c. Auto transverse control d. Real wheel loading e. Many load magnitude
	FHWA		a. Study the influence of tire pressure b. Assess the impact of wide based single tires on flexible pavement performance c. Validate Superpave Analysis system / models d. Test thin concrete overlays e. Relate ALF to field conditions	a. Full - Scale loads b. Full - Scale Pavements c. Controlled Environmental condition (temperature) d. Traffic Wander can be specified e. Energy efficient design
	LTRC	13' wide lanes by 215' long	a. Base Course Comparitive Study (9 test lanes) b. Rubberized Asphaltic Concrete Study (3 test lanes)	a. Operates around the clock without having to be monitored b. Simulates Truck wander
	TxDOT		a. Evaluate local base material b. Evaluate 2 inplace hot recycling processes c. Study AASHTO 4th Power Rule d. Evaluate effect of water on pavement deterioration	a. Uses standard Truck components; acts like a truck b. Mobile c. Applies std. Truck loads in accelerated application d. Travels in one direction e. Can induce 'wander' like conventional traffic f. Can induce 25% over load; can accommodate Super Single tires; various Suspensions; tire pressures etc.
	CSIR, Pretoria, South Africa		Over 20 years there have been many : Currently it is to evaluate labour - intensity constructed bases.	a. Mobile : used on real roads, trial sections, or in "laboratory" b. Well - Proven, reliable c. Many HVS - associated measurement devices developed d. Underpins South Africa Pavement engineering : Provides invaluable structural evaluation data

RESPONSES TO QUESTIONNAIRE ON ACCELERATED PAVEMENT TESTING

	Agency Name	Dimensions of pavement section/model	Objectives	Advantages
Mobile, linear mechanical loading devices	Univ. of California, Berkeley		a. Evaluation of including an asphalt treated permeable base into asphalt concrete b. Comparision of dense-graded asphalt concrete & asphalt rubber pavements overlays c. Validation of UCB fatigue analysis and design procedure d. Evaluation of rutting under different tire types: bias & radial dual, super singular aircraft tires e. Validation of Caltrans rapid-setting concrete pavement mix design for long-life pavements	a. Mobile b. Wide range of loads, load types can be applied c. Uni and bi - directional d. Large database testing from UCB, CRREL, Finland/Sweden, and S. Africa (20 years of results) e. Established procedures are available for acquiring and analyzing data
	Technical Research Center (VTT)		a. Unbound granular base course materials b. Thaw (frost) c. Special bituminous base courses	a. Full temperature control (heating/cooling) b. Mobile over short and long distances.
	ARRB Transport Research Ltd., Australia		a. Provide a quantified guide to the relative performance b. Evaluate the performance of a marginal material modified by the addition, in situ, of bitumen/cement and slag/lime blends c. Compare the performance of two cement-stabilised flyash pavements with that of a 'control' cement-stabilised crushed rock pavement and develop fatigue performance models for these materials suitable for design purposes. d. Examine the performance of pavements deep-lift stabilised in situ (up to 360 mm) with a slag/lime blend and compare observed pavement lives with fatigue life prediction models currently in use in Australia. e. Verify the US Army Corps of Engineers classification scheme for lateritic gravels for roads and airfield pavements f. Determine the structural adequacy of a pavement consisting of a geotextile-reinforced seal over a prepared clay foundation and determine how performance is influenced by transverse location of the load and the presence of water.	a. proven technology b. average operating time about 70%, average loss time due to mechanical breakdown about 10%. c. mobile and relocatable d. traffics pattern is typical of normal in-service pavements e. can apply loads up to twice the Standard Axle load f. pavements are constructed using typical methods associated with in-service pavements g. depending on pavement type, can traffic up to three (4 m long) test sections at the same time h. pavement heating system (as also used at FHWA); temperature control up to 60°C at an accuracy of ±2°C; also pavement cooling system
Fixed, circular mechanical loading devices	IVT - ETH, Honggerberg, CH-8093 Zurich		a. Reports ASTRA / UVEC b. Cement Stabilisation c. Cold mix layer d. Stone mastix surface layer e. Pave setting	a. Fast testing of known pavement design b. Variation of wheel loads c. Variation of speeds d. Verification of new pavement designs under "real" and controlled conditions e. Research work for standards
	Saskatchewan Department of Highways and Transportation, Saskatchewan		a. Testing the effects of subgrade moisture changes on swelling soils b. Measuring the movement of various highway layers to various loads c. Investigating the effects of reduced tire pressure on low volume roads d. Experimenting with various sensors inbedded in the road e. Pavement performance studies (rutting, cracking, etc.) f. Investigating the performance of thin membrane surfaces.	a. Can freeze a portion (1/5th) of the track to simulate freeze - thaw conditions b. Can flood the sideslope of a portion (1/5th) of the track to investigate subgrade saturation c. Can elevate the temperature inside the track to 42degrees Centigrade d. Have a sprinkler system to simulate rain e. Can monitor stresses and strains and movements at various locations and depths

	Agency Name	Dimensions of pavement section/model	Objectives	Advantages
Fixed, circular mechanical loading devices	Institute of Engineering, UNAM, Mexico			
	Centro de Estudios y Experimentación de Obras Públicas (CEDEX)		a. Comparison of performance of different pavements b. Comparison of performance of different subgrades c. Comparison of performance of different materials d. Calibration of models	a. Very high output, in comparison with other linear facilities b. Simultaneous testing of 6 pavements in the linear stretches c. Accelerated abrasion in curves, for testing wearing courses d. Pavements constructed in a concrete box, allowing simulation of water level f. Full automatized data adquisition system
	LCPC - France		a. Comparision of fatigue and rutting performances between very various materials (hot and cold asphalt mixes, concrete,...) and structures b. Comparision between site and lab materials performance c. Study of new pavement materials d. Study of strain and stress measurement methods e. Assessment of pavement and materials behavior modelling	a. Acceleration (1 year / week) b. Realistic construction of structures (as on job site) c. Up to 4 materials / structures and 4 axle types per test d. Site measurement e. Lab and modelling environment f. Accumulated experience on more than 15 years with about 50 * 10^6 charges applied and 150 experiments. Adjustable radius of rotation.
	Univ. of Washington			
Other	BAST	Length - 38 m, Width - 7.5 m (= 2 travel lanes), Depth - 3.0 - 3.5 m	Recent: Using recycling materials in the unbound layer of asphalt construction	a. To compare good prooved construction with new constructions within a few months b. Frosting and heating equipment c. Variable ground water - level

RESPONSES TO QUESTIONNAIRE ON ACCELERATED PAVEMENT TESTING

	Agency Name	Weaknesses	Strategic Plans
Full-scale test tracks with loaded trucks	Public Works Research Institute, Japan	a. Maintenance cost and operation cost b. System down caused by complicated control system c. Low loading frequency...1300 times per a day	When new materials and construction techniques were developed, the Pavement Test Field examine them before actual field application
	NCAT		
	Virginia Tech.	a. It is designed "not to fail soon" b. Very limited budget c. Short length	The facility will be used to evaluate VDOT mixes, the pavement design method, drainage technique, and geosynthetic effectiveness. In addition, the road will allow to quantitively measuring the effect of environment by using the all weather facility. Calibration of pavement survey equipment such as profilometer, FWD, and GPR.
	MnDoT	One location in state	a. Move towards a Mechanistic / Empirical Design for Mn/DoT / partners b. Continue to monitor test cells c. Continue to partner with others who are working towards the same goals d. Provide Minnesota better longer lasting pavements using Mn/Road information to better understand how pavements react to seasonal variations and traffic
	The Circle Test Track Vuis - CESTY (KDS)	a. Water thermal regime of the roadbed cannot be changed b. Climatic conditions cannot be changed	This time the influence of axle load 11.5 kN are being tested. Preparing projects aiming at verifying the working time of various kinds of road repairs.
	WesTrack		
Full-scale test tracks with loaded trucks	Ohio University	Limited no. load repititions per day for long term testing	

RESPONSES TO QUESTIONNAIRE ON ACCELERATED PAVEMENT TESTING

	Agency Name	Weaknesses	Strategic Plans
Fixed, linear mechanical loading devices	Delft University of Technology, Road and RailRoad Laboratory, Netherlands	a. Non mobile b. No cooling, no real moisture control c. Relatively low speeds d. High power consumption (relative to e.g. ALF) e. Not enough space to have several series of test sections	For the next 3 years research into the rutting susceptibility of different asphalt mix types and the deformation behavior of these mixes at different temperatures, in conjunction with triaxial material's testing and modelling of the constitutive (stress-strain) relations for these mixes.
	Ohio University	Limited no. load repititions per day for long term testing	
	Technical University of Denmark, Denmark	a. Short test section b. One - way loading not possible c. Old, requires frequent maintenance	
	Kansas State University		
	Laboratoire des Voies de Circulation - Laboratory of traffic facilities Ecole Polytechnique Fédérale de Lausanne - Swiss Federal Institute of Technology	Short length of test section (no roughness evaluation)	Now working for European Union research project PARIS and AMADEUS and for the swiss road authorities
loading devices	INDOT	Test pad is 20 * 20 feet	

RESPONSES TO QUESTIONNAIRE ON ACCELERATED PAVEMENT TESTING

	Agency Name	Weaknesses	Strategic Plans
Fixed, linear mechanical	University of Nottingham	a. Not full scale loading and relatively low speed b. Flexure testing requires weak lower layers to generate fatigue cracking c. Testing ocassionally goes to 250,000 cycles but usually limited to 100,000 d. Obtaining small quantities of hot material from an asphalt plant e. Requires special arrangements to reduce heat loss during delivery	The objective of validation of pavement performance models based on laboratory derived mechanical properties of the individual materials will be sustained. Support from industrial and government bodies will be continued for research into improving pavement performance. A flexible approach to the test programme is necessary so that commercial work can be included for manufacturers requiring short test programmes on new products. This type of work increases the number of contacts in the industry and can lead to further research projects.
Mobile, linear mechanical loading devices	Research Institute of Highway, Ministry of Communications, P. R. China	a. The ambit temperature couldn't be controlled b. Loading speed is instant	Going to do some work with LTPP with ALF now
	FHWA	a. Load speed is limited to 12 mph b. Moisture content is unconditional c. Need 2 large cranes to move longitudinally	
	LTRC	a. No support for the device (I.e., US company out of business) b. Difficulty in getting contractors to submit bids for construction of test lanes c. High cost of construction and operations d. Difficulty in moving the ALF machine	
	TxDOT	a. No Climate control b. Is one of a kind	1. Evaluate truck component / pavement interaction 2. Evaluate / verify AASHTO 4th Power Rule 3. Evaluate field performance of new materials, procedures, processes 4. Develop performance - based models 5. Evaluate rehab options
	CSIR, Pretoria, South Africa	Speed of loading - regarded as secondary	A strategy is essential to maximise from the use of such facilities. Our current strategy is geared to to the current need to provide most cost-effective pavements for lower volume, lower utility roads. This entails investigating various base types and structures suited to this type of usage rather than the frequency - type roads.

RESPONSES TO QUESTIONNAIRE ON ACCELERATED PAVEMENT TESTING

	Agency Name	Weaknesses	Strategic Plans
Mobile, linear mechanical loading devices	Univ. of California, Berkeley	a. Expensive to operate but relative to benefits that are possible, the testing is not expensive b. Small test section (8 * 1 m) c. Speed of the wheel	
	Technical Research Center (VTT)	Low speed	HVS - NORDIC is owned 50/50 by Finland (the Technical Research Center of Finland - VTT and the Finnish National Road Administration) and Sweden (the Swedish Road and Transport Institute - VTI). It is mobile and is used basically one year in Finland, one year in Sweden etc.
	ARRB Transport Research Ltd., Australia	a. Moisture environment cannot be controlled (unless device is located in a shed or similar) b. One speed (20 km/h) c. One suspension type (modified airbag) d. Longitudinal grade of test pavement restricted to 1.5% for safe operation e. Single axle operation f. Maximum pavement test length is 12 m	The Austroads Pavement Research Group produces a "Strategy for Pavement Research and Development" on a regular basis and pavement/materials research in Australia, including ALF work, is directly linked to this Strategy. The Australian Asphalt Pavement Association also has a Strategy which is also linked with the Austroads strategy. (Austroads is the association of Australian State Transport Agencies, like AASHTO say).
Fixed, circular mechanical loading devices	IVT - ETH, Honggerberg, CH-8093 Zurich	None	No; Research follows as closely as possible to demands of state and federal DOT's
	Saskatchewan Department of Highways and Transportation, Saskatchewan	a. Outdated electronics and software systems b. Lack of funding c. Shortcomings with the original construction primarily pertaining to gantry design	Test track will likely close within the year unless new funding sources can be located. The current experiment will be completed.

RESPONSES TO QUESTIONNAIRE ON ACCELERATED PAVEMENT TESTING

	Agency Name	Weaknesses	Strategic Plans
Fixed, circular mechanical loading devices	Institute of Engineering, UNAM, Mexico		The test track has been very useful in the long-term research program. Normally the research programs include, besides the test track, full scale testing in the field and materials fatigue characterization taking into account fatigue cracking and permanent deformation. Testing is carried out in a servo-hydraulic MTS machine with an environmental chamber, upto failure or 1,000,000 cycles
	Centro de Estudios y Experimentación de Obras Públicas (CEDEX)	It is not possible a total control of weather conditions	There are 3-year programs, according with the Ministry of Public Works
	LCPC - France	a. Climatic control only by season choice b. Rather expensive for minor tests.	- No strategic plan, since a lot of experimentations have been carried out since 15 years - During the next years emphasis will be set on a. unbounded base courses b. Rutting c. Cold asphalt mixes.
	Univ. of Washington		
Other	BAST	No wheel - passing	

RESPONSES TO QUESTIONNAIRE ON ACCELERATED PAVEMENT TESTING

	Agency Name	Future Plans	Comments/ Recommendations	Name	Title
Full-scale test tracks with loaded trucks	Public Works Research Institute, Japan		Remote and radio control system is not recommended because of complicated system. Actual tire configuration should be considered. However, actual vehicles are not always necessary.	Mr. Takuya Ikeda	Head, Pavement Division
	NCAT			Ray Brown	Director
	Virginia Tech.			Imad L. Al-Qadi	Professor
	MnDoT	a. Interested in regional partnerships b. The University of Minnesota is currently doing Accelerated testing of concrete pavements			
	The Circle Test Track Vuis - CESTY (KDS)			Ing - Zdenek Lovecek	
	WesTrack			Sirous	
Full-scale test tracks with loaded trucks	Ohio University		Larry Scofield at ADOT is familiar with both Accelerated Pavement Load facility and Ohio SHRP Test Pavement	Bill Edwards	Research Engineer

RESPONSES TO QUESTIONNAIRE ON ACCELERATED PAVEMENT TESTING

	Agency Name	Future Plans	Comments/ Recommendations	Name	Title
Fixed, linear mechanical loading devices	Delft University of Technology, Road and RailRoad Laboratory, Netherlands			Jacob Groenendijk	Research Engineer
	Ohio University		Larry Scofield at ADOT is familiar with both Accelerated Pavement Load facility and Ohio SHRP Test Pavement	Bill Edwards	Research Engineer
	Technical University of Denmark, Denmark		South African Heavy Vehicle Simulator (HVS) will be preferred in case of getting a new APT facility	Per Ullidtz	Associate Professor
	Kansas State University			Hani G. Melhem	Associate Professor and Director
	Laboratoire des Voies de Circulation - Laboratory of traffic facilities Ecole Polytechnique Fédérale de Lausanne - Swiss Federal Institute of Technology		There is a good information in the OECD publications (as for example about the Nardo experiment and the FORCE project) and description of a large number of full scale facilities in the world		
loading devices	INDOT	1. INDOT is interested in regional and national partnerships; Currently, INDOT-APT Facility is used to validate the superpave asphalt mixtures specifications 2. INDOT-Materials and Tests division is in the process of acquiring the Smaller - Laboratory Purdue Wheel Tracking Device (PURWHEEL)		Khaled A. Galal	Pavement and Materials Research Engineer

RESPONSES TO QUESTIONNAIRE ON ACCELERATED PAVEMENT TESTING

	Agency Name	Future Plans	Comments/ Recommendations	Name	Title
Fixed, linear mechanical	University of Nottingham	It has been recognised that there is a demand for wheel loading devices and the feasibility of having a full scale facility is now under construction.	1. It has been recognised that there is a demand for wheel loading devices and the feasibility of having a full scale facility is now under construction 2. The use of pavement instrumentation is essential for effective pavement research. 3. Smaller test facilities can have a role in the planning of large scale tests by using them to carry out preliminary tests which can rank the materials or products to be tested and perhaps eliminate some. 4. Mobile APTs can test new or old pavements.	B. V. Brodrick	Senior Experimental Officer
Mobile, linear mechanical loading devices	Research Institute of Highway, Ministry of Communications, P. R. China		ALF is a very good tool for us to do some study work on asphalt pavement. The Accelerated Pavement Test (APT) is a low cost and high benefit experiment method, so it is widely used in the world. Though APT facility has weaknesses, but APT can do much work for us.	Meng Shutao	Associate Research ALF Project Manager
	FHWA			James A. Sherwood	Research Highway Engineer
	LTRC			William "Bill" King, Jr., P.E.	Pavement Research Facility
	TxDOT			Kenneth W. Fults, P.E.	Director of Pavements
	CSIR, Pretoria, South Africa		a. Have a clearly defined strategy covering the first 3 years in place, with a reasonable idea of the next 7 years b. Understand that the APT facility is simply a test : ensure that you have all the monitoring devices from which to determine performance c. Make sure that you have the necessary team in place to optimise the facility : technical to manual and maintain the facility; engineering to direct and coordinate, and ultimately interpret the data; support to assist with data processing especially.	Dr. S. V. Kekvwick	Proj. Manager : Pavement Engineering and HVS/APT

	Agency Name	Future Plans	Comments/ Recommendations	Name	Title
Mobile, linear mechanical loading devices	Univ. of California, Berkeley		A major benefit of the HVS tests is the year of testing experience in South Africa which are drawn on in the program. The technology transfer component of the project greatly helped the program get set up and reduced much of the learning curve, allowing us to reduce the operational problems and be able to focus on obtaining technically valuable results from the beginning of HVS testing. Initial guidance in establishing test plane, data collection, and data reduction made this program more efficient from the beginning.		
	Technical Research Center (VTT)			Matti Huhtala	Chief Research Scientist
	ARRB Transport Research Ltd., Australia			Kieran Sharp	Principal Research Scientist
Fixed, circular mechanical loading devices	IVT - ETH, Honggerberg, CH-8093 Zurich			MARKUS CAPREZ	Director
	Saskatchewan Department of Highways and Transportation, Saskatchewan			Bill Pacholka	Director, Testing Services

RESPONSES TO QUESTIONNAIRE ON ACCELERATED PAVEMENT TESTING

	Agency Name	Future Plans	Comments/ Recommendations	Name	Title
Fixed, circular mechanical loading devices	Institute of Engineering, UNAM, Mexico			Prof. Santiago Corro Caballero	Coordinator of Land Transportation
	Centro de Estudios y Experimentación de Obras Públicas (CEDEX)			Aurelio Ruiz	Engineer
	LCPC - France			Gordan Jean Louis	Senior Research Manager
	Univ. of Washington	WSDOT will likely team with Cal APT, Westrack, or MnRoad for any needed APT activity. At this point we have an emerging association with UC Berkeley and Caltrans.	A small, laboratory rolling wheel track was constructed in the 1950's. The last time it was used was the early 1980's for asphalt concrete fatigue relationships. The device was dismantled and sent to dump. WSDOT / Washington State Univ. had a full-scale circular test track - constructed in the 1960's, it was dismantled in the early 1990's. The last tests were run in the 1980's. Both structural evaluation (fatigue / rutting) and studded tire wear were performed. Thus, at this time, no APT facility exist in Washington state.	Joe P. Mahoney	Professor
Other	BAST				

	Agency Name	Agency	Phone	Fax	E-mail
Full-scale test tracks with loaded trucks	Public Works Research Institute, Japan	Public Works Research Institute	+81-298-64-2538	+81-298-64-0778	ikeda@pwri.go.jp
	NCAT	NCAT	334-844-6228	334-844-6248	rbrown@eng.auburn.edu
	Virginia Tech.	Virginia Tech	504-231-5262	504-231-7532	alqadi@vt.edu
	MnDoT				
	The Circle Test Track Vuis - CESTY (KDS)	The Circle Test Track Vuis - CESTY (KDS)			
	WesTrack	WesTrack			sirous@nce.reno.nv.us
Full-scale test tracks with loaded trucks	Ohio University	Ohio University	740-654-6711 EX. 277	740-687-9497	

RESPONSES TO QUESTIONNAIRE ON ACCELERATED PAVEMENT TESTING

	Agency Name	Agency	Phone	Fax	E-mail
Fixed, linear mechanical loading devices	Delft University of Technology, Road and RailRoad Laboratory, Netherlands	Delft University of Technology, Road and RailRoad Laboratory	+31 15 278 2325	+31 15 278 3443	J.Groenendijk@ct.tudelft.nl
	Ohio University	Ohio University	740-654-6711 EX. 277	740-687-9497	
	Technical University of Denmark, Denmark	Technical University of Denmark	+45 45 25 1518	+45 45 93 6412	pullidtz@ivtb.dtu.dk
	Kansas State University	Kansas State University	785-532-1584	785-532-7717	melhem@ce.ksu.edu
	Laboratoire des Voies de Circulation - Laboratory of traffic facilities Ecole Polytechnique Fédérale de Lausanne - Swiss Federal Institute of Technology				
loading devices	INDOT	INDOT - Division of Research	765-463-1521	765-497-1665	KHALED_GALAL@HOTMAIL.COM

RESPONSES TO QUESTIONNAIRE ON ACCELERATED PAVEMENT TESTING

	Agency Name	Agency	Phone	Fax	E-mail
Fixed, linear mechanical	University of Nottingham	University of Nottingham, Dept. of Civil Engg.	0115 951 3912	0115 951 3898	barry.brodrick@Nottingham.ac.uk
Mobile, linear mechanical loading devices	Research Institute of Highway, Ministry of Communications, P. R. China	Research Institute of Highway, Ministry of Communications, P. R. China		86-10-62063247 or 62014130	mengesh@public.east.cn.net
	FHWA	FHWA	703-285-2619	703-285-2767	JIM.SHERWOOD@FHWA.DOT.GOV
	LTRC	LTRC	504-749-8900	504-749-1004	king@louisiana.com
	TxDOT	TxDOT	512-465-7741	512-465-3681	kfults@Mailgw.dot.state.tx.us
	CSIR, Pretoria, South Africa	CSIR, Pretoria, South Africa	+2712 841 3080	+2712 841 3095	skekwick@csir.co.za

RESPONSES TO QUESTIONNAIRE ON ACCELERATED PAVEMENT TESTING

	Agency Name	Agency	Phone	Fax	E-mail
Mobile, linear mechanical loading devices	Univ. of California, Berkeley				
	Technical Research Center (VTT)	Technical Research Center (VTT)	+ 358 9 4564960	+ 358 9 463251	Matti.Huhtala@vtt.fi
	ARRB Transport Research Ltd., Australia	ARRB Transport Research Ltd 500 Burwood Highway Vermont South Vic. 3133 Australia	+61-3-9881 1555	+61-3-9887 8104	kierans@arrb.org.au
Fixed, circular mechanical loading devices	IVT - ETH, Honggerberg, CH-8093 Zurich	IVT - ETH, Honggerberg, CH-8093 Zurich	+ 41 1 633 25 32	+ 41 1 633 10 62	
	Saskatchewan Department of Highways and Transportation, Saskatchewan	Saskatchewan Department of Highways and Transportation	306-787-4917	306-787-4582	bill.pacholka.hi0@govmail.gov.sk.ca

	Agency Name	Agency	Phone	Fax	E-mail
Fixed, circular mechanical loading devices	Institute of Engineering, UNAM, Mexico	Institute of Engineering, UNAM, Mexico	+52 (5) 622-3200 / 550-0388	+52 (5) 616-2894 / 616-1514	scc@pumas.iingen.unam.mx
	Centro de Estudios y Experimentación de Obras Públicas (CEDEX)	Centro de Estudios y Experimentación de Obras Públicas (CEDEX)	34-91-335 7860	34-91-335 7822	aruiz@cedex.es
	LCPC - France	LCPC - France - (BP 19 - 44340 - Bouguenais)	33 (2) 40 84 58 05	33 (2) 40 84 59 94	Jean-Louis.Gourdon@lcpc.fr
	Univ. of Washington	Univ. of Washington	206-685-1760	206-543-1543	jmahoney@u.washington.edu
Other	BAST				