The Superpave Mix Design System: Anatomy of a Research Program

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The research reported herein was performed under NCHRP Project 9-42 by the North Central Superpave Center (NCSC) at Purdue University as the prime contractor. TDC Partners of Alexandria, Virginia, was the subcontractor on the project and, in turn, had subcontracts with Nichols Consulting Engineers, Fugro Consultants, Inc., and the Heritage Research Group.

Dr. Rebecca S. McDaniel, Technical Director of the NCSC, was the principal investigator. The other authors are Dr. Rita B. Leahy, formerly with Nichols Consulting Engineers and now with the California Asphalt Pavement Association; Mr. Gerald A. Huber, of the Heritage Research Group; Mr. James S. Moulthrop of Fugro Consultants, Inc.; and Mr. Ted Ferragut, principal of TDC Partners, Inc., now retired.

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ABSTRACT

The asphalt research program conducted as part of the Strategic Highway Research Program was the most focused asphalt research program ever. Intense research activity over a nominal five-year period at a cost of $50 million dollars led to sweeping changes in how asphalt materials are specified, tested and designed. The products of this research, known collectively as the Superpave mix design system or simply Superpave, are used across the US and internationally. This report describes how such a large-scale research effort was conceived, funded, and managed. It outlines the research and implementation efforts that brought the products into routine use. Lastly, it summarizes some of the key lessons learned in the process of conducting such a large-scale program.

The findings outlined in this report were garnered through interviews with over 70 people who were involved in the research and implementation efforts as well as reviewing reports, letters, diaries, meeting minutes and other documents.

EXECUTIVE SUMMARY

The Strategic Highway Research Program (SHRP, pronounced "Sharp") was an unprecedented research effort. It was the largest, most highly focused research effort in the United States since the AASHO Road Test of the late 1950s and went far beyond the Road Test in its breadth and scope. While SHRP was aimed at developing high-payoff products in six focused areas of national need, the Asphalt Research Program was the largest effort in terms of funding and was arguably the most successful. This program eventually led to the development of the Superpave system for the design of asphalt mixtures, which has changed asphalt technology in the U.S. and has had an impact around the world.

Superpave has created change in the entire asphalt industry, including asphalt binder suppliers, aggregate suppliers, hot-mix producers, contractors, and specifying agencies at all levels. Superpave introduced new concepts for material testing and selection, new test protocols, new equipment, a new mix design method and new performance testing tools. Implementation has required substantial investments in equipment and training far exceeding the initial research investment. In fact, the implementation process is still ongoing today (2011), over 18 years since the conclusion of the research.

The SHRP Asphalt Research Program was a success not only because of its technical developments but also as a result of its organization. The methods of funding, administration, organization, and decision-making all contributed to its success, though some elements of the program were certainly less successful than others.

Perhaps SHRP's greatest achievement is the implementation of its research results. From the outset, SHRP's objective was to implement the technology that was developed. The focus of the entire research effort was on high-payoff, implementable research results. As a result, some efforts to initiate implementation began before the research was completed, at times to the consternation of the asphalt community.

This report summarizes the findings of a study to document the history of the SHRP Asphalt Research Program from the initiation of the research through the eventual implementation and refinements of its products. The report also addresses the organizational structure of this large-scale program. This report is not a critique of the research results. Instead, it is intended to document the processes used to develop the research products and the methods used to resolve the technical and organizational barriers encountered.

It is hoped that this accounting of the technical decisions made during SHRP will provide an understanding of how the Superpave mix design system came together and will identify where refinements may be possible in the future. In some instances, decisions had to be made to pursue one path over another due to budgetary, time, or technological constraints. As technological advances occur in the future, or as time and funding become available, these alternate paths may be fruitful areas of inquiry. Second, understanding the successes and disappointments of SHRP can help with the design of future focused research programs and implementation efforts.

RESEARCH APPROACH

The SHRP Asphalt Research program generated thousands of pages of reports, meeting minutes, papers, articles, and more. In documenting the history of this program, the research team reviewed written documents from published sources. In addition, the team reviewed the personal files, notes, and diaries of many of the key personnel involved in the program. The team also searched through archives of slides, notes from presentations, and other documents held at TRB, FHWA, and elsewhere.

Much of the story behind such a large-scale research program as the SHRP Asphalt Research program, however, is never written down. To gather this unwritten information, the research team conducted over 70 interviews with key personnel from all aspects of the program. Subjects of these interviews included key researchers and graduate students involved in the research, the management staff of the SHRP office, FHWA staff, hot-mix producers, binder and aggregate suppliers, state Department of Transportation personnel, equipment manufacturers, industry association representatives and others. Most interviews were conducted in person, but some were done by telephone between April 2006 and September 2010. Notes from most interviews were reviewed by the subjects to ensure accuracy. Each interview provided an insight into the program from a different perspective, yet common themes emerged from the disparate quarters. These insights and themes are reflected in this report.

Three major phases of work are described here to provide a complete picture of the program. The pre-research phase, prior to 1987, was when the seeds of the program were sown. The research phase began in 1987 and lasted into 1993. Implementation was considered during the final years of the research phase, but the main implementation phase began in 1993. (These phases are more fully defined in Chapter 2 and described individually in some detail in Chapters 3, 4 and 5.)

RESEARCH FINDINGS

This report summarizes how the SHRP Asphalt Research Program products – the Performance-Graded binder specification, the Superpave mix design system, and supporting test protocols and equipment – were developed and evolved. The implementation of the products of this research program stimulated change in every facet of the asphalt industry. Superpave pavements have been shown to perform better, in general, than previous mixes. Overall, Superpave is recognized as one of the major success stories of SHRP.

Not all of the technical efforts under the Asphalt Research Program were entirely successful, however. The planned performance prediction models are still being sought through other research efforts. Moisture damage still occurs in pavements, and there is no widely accepted test method to prevent its occurrence.

From a non-technical viewpoint, there were ancillary benefits of the SHRP Program. Many young engineers and researchers were brought into the research and/or implementation efforts at an early stage and have gone on to have illustrious careers. More established researchers were able to make a mark and solidify their reputations. And, as might be expected in such a large-scale, cutting-edge effort, egos clashed and disputes arose from time to time.

In addition, the review revealed a number of lessons learned. In fact, the main findings of this project may best be expressed as lessons learned through the entire research and implementation effort stretching over a period of more than 20 years. The following lessons may benefit future large-scale research programs.

- Make decisions transparent and firm.
- Document the decisions made.
- Ensure strong technical leadership with management skills
- Have a clear vision of the scope, size and complexity of the problem.
- Recognize the “politics of ideas” and that researchers will defend their positions.
- Develop an atmosphere fostering teamwork and cooperation rather than competition.
- Try to ensure researchers have the time and resources to be dedicated to the effort.
- For major issues, consider forming research hubs to help develop a sense of partnership or explore technological options to do the same.
- Buffer the competing interests of various stakeholders – balance risk and reward.
- Build a cooperative community to help others adopt the new technology.
- Recognize the size of the implementation effort – it may be even greater than the size of the research endeavor.
- Ensure continued support for the implementation process.
- Involve researchers in the implementation effort and users in the research effort.
- Communicate clearly with the eventual users of the research results– give them an idea of what is coming but make it clear what is preliminary and what is ready to implement.
- Get the technology out to the users – strawman specifications, first article procurements and pooled-fund equipment buys are very effective strategies to get people to try new technologies and get feedback to refine the products.
- Benchmark the status before, during and after implementation to document the success – or lack thereof – of the research and implementation effort.

CHAPTER 1. BACKGROUND

The Strategic Highway Research Program (SHRP, pronounced "Sharp") was an unprecedented research effort. It was the largest, most highly focused research effort in the United States since the AASHO Road Test of the late 1950s and went far beyond the Road Test in its breadth and scope. While SHRP was aimed at developing high-payoff products in six focused areas of national need, the Asphalt Research Program was the largest effort in terms of funding and was arguably the most successful. This program eventually led to the development of the Superpave system for the design of asphalt mixtures, which has changed asphalt technology in the U.S. and has had an impact around the world.

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This report summarizes the findings of a study to document the history of the SHRP Asphalt Research Program from the initiation of the research through the eventual implementation and refinements of its products. The report also addresses the organizational structure of this large-scale program.

1.1 PURPOSE OF THIS HISTORY

This project was initiated to document the asphalt technology developed and implemented through the SHRP Asphalt Program and the processes used throughout the research and implementation efforts. The focus is on the Asphalt Research Program in particular. In discussing some organizational and administrative issues, however, some comments may apply to the SHRP Program in general.

This report is not a technical critique of the research results. Instead, it is intended to document the processes used to develop the research products and the methods used to resolve the technical and organizational barriers encountered.

It is hoped that this accounting of the technical decisions made during SHRP will provide an understanding of how the Superpave system came together and will identify where refinements may still be possible in the future. In some instances, decisions had to be made to pursue one path over another due to budgetary, time, or technological constraints. As technological advances occur in the future, or as time and funding become available, these alternate paths may be fruitful areas of inquiry. Second, understanding the successes and disappointments of SHRP can help with the design of future focused research programs and implementation efforts.

1.2 APPROACH

The SHRP Asphalt Research program generated thousands of pages of reports, meeting minutes, papers, articles and more. In documenting the history of this program, the research team reviewed written documents from published sources. In addition, the team reviewed the personal files, notes and diaries of many of the key personnel involved in the program who were kind enough to grant access to their files. The team also searched through archives of slides, notes from presentations and other documents held at TRB, FHWA and elsewhere.

Much of the story behind such a large-scale research program as the SHRP Asphalt Research program, however, is never written down. To gather this unwritten information, the research team conducted over 70 interviews with key personnel from all aspects of the program. (A listing of the people interviewed is included in Appendix A.) Subjects of these interviews included key researchers and graduate students involved in the research, the management staff of the SHRP office, FHWA staff, hot-mix producers, binder and aggregate suppliers, state Department of Transportation personnel, equipment manufacturers, industry association representatives and others. (Many of those interviewed are pictured in the photographs in Appendix C.) Most interviews were conducted in person, but some were done by telephone between April 2006 and September 2010. Notes from most interviews were reviewed by the subjects to ensure accuracy. Each interview provided an insight into the program from a different perspective, yet common themes emerged from the disparate quarters. These insights and themes are reflected in this report.

Three major phases of work are described here to provide a complete picture of the program. The pre-research phase, prior to 1987, was when the seeds of the program were sown. The research phase began in 1987 and lasted into 1993. Implementation was considered during the final years of the research phase, but the main implementation phase began in 1993. These phases will be more fully defined in Chapter 2.

Each of these phases is investigated and documented in this report in Chapters 3, 4 and 5. The report is generally structured by topic areas within a chronological framework. In other words, within the three phases, topics including binders, mixtures (including aggregates, performance testing and modeling) and construction (in the implementation phase) are addressed. The history will also examine linkages and interrelationships between the different phases and topics.

Finally, the report will conclude with a discussion of the lessons learned in both technical and programmatic terms. The benefits and pitfalls of a large-scale research program will be explored, and recommendations for the conduct of future research and implementation projects will be offered.

1.2.1 Technical Issues in this Report

This report is not intended as a technical critique of the research results; hence it does not focus on deep discussion of the research findings. Some level of detail, however, is necessary to tell the story of how the Superpave system was developed and implemented. Those who want detailed technical information on how the research was conducted and the significance of the findings should refer to the project reports that are listed in the references. Readers who are not familiar with asphalt materials and mixtures may want to review Appendix D, which describes how asphalt mix design works.

In some cases, anecdotes or "stories" have been included to illustrate some of the behind-the-scenes discussions and issues. These are presented in a less formal style than typically used in a technical report because they are not necessarily technical issues and, frankly, to make them more entertaining for the reader. These anecdotes have been set off in boxes to emphasize that they are somewhat peripheral to the main story.

1.3 APPLICABILITY OF RESULTS TO PRACTICE

There are two key benefits or ways the results of this project can be used:

- The SHRP Asphalt Research Program was one of the most successful research and implementation projects in the history of the US highway program. As such, this history will document how the Superpave system came to be and how its implementation was promoted. It will summarize the decisions made, as well as how and why they were made. This may identify promising lines of research that were not or could not be pursued due to various constraints (technical and non-technical, such as time, funding, technology, "politics," etc.)
- This history will also describe the processes and organizational features that worked or did not work in both the research and implementation phases. This assessment of the administration of the program can serve as a guide for future research and implementation efforts.

CHAPTER 2. TIMELINE OF THE SUPERPAVE PROGRAM

The SHRP Asphalt Research Program lasted for a clearly defined period of time from the initial funding in 1987 into 1993. Events and issues prior to 1987 provided the impetus for undertaking the large-scale Strategic Highway Research Program. In 1993, the SHRP research was concluded and the implementation phase began in earnest. These three time periods, pre-research, Research, and Implementation, are explored in this report. This timeline provides a chronological framework for the report as well as reflecting the different activities, issues and needs that existed within these time periods.

Subsequent chapters of this report document and explore each of these phases. The first is the pre-research phase from the early 1980s until the initiation of the SHRP Program in 1987. This phase covers the seeds of the research program. It addresses the challenges that were being faced in the early 1980s and how the idea of a focused research effort transformed into the launching of SHRP. The Strategic Transportation Research Study (STRS) report, described in Chapter 3, was prepared during this phase and the groundwork was laid to secure the legislation that funded the program.

The SHRP Research Phase occurred from 1987, when the legislation was passed to fund the program, to 1993, the end of the nominal five-year program. Research plans were finalized and contracts were awarded during this time period. The overall management and administration of the research program are explored in this phase, as are the technical deliberations and decisions. Alternate paths that were abandoned for a variety of reasons are identified, as they may be fruitful research paths to explore in the future.

In 1993 the early implementation efforts of the SHRP asphalt team transitioned into a sustained implementation phase. Decisions were made early on in this phase as to who would take the lead in promoting implementation and how they would do so. Implementation efforts gradually evolved into acceptance and adoption of the new system. The system is continuing to evolve to this day as research continues to refine the system for the future.

2.1 MAJOR PLAYERS AND ROLES

A large number of people were involved in the development and implementation of the SHRP Asphalt Research Program. Inevitably, the contributions of some people will not be mentioned specifically in this report, though every effort has been made to be as thorough as possible. No one was intentionally omitted, but in a program this large and, in some aspects, sparsely documented, it is impossible to mention everyone who was involved. In some cases, specific individuals are not cited by name but are rather referred to by the group or organization in which they were involved; this may be because the exact individual responsible for some decision or suggestion could not be ascertained or because they represent a larger group's opinion or involvement. Some of the key groups that will be discussed in this report are enumerated below; other groups and individuals will be introduced in later chapters. Appendix B includes listings of membership in the key groups involved in this program. Appendix C is a photograph album with many pictures of some of the people involved in Superpave research, management and implementation.

The individuals involved in the pre-research phase are somewhat more indistinct than the other phases, especially those individuals working behind the scenes to secure funding through the legislation. Those involved in the grassroots support for a national research program are also somewhat obscure. Obviously the American Association of State Highway and Transportation Officials (AASHTO) and the state Department of Transportation (DOT) leaders had prominent roles to play here. Thomas D. Larson and the Steering Committee for a Strategic Transportation Research Study: Highways were instrumental in laying the foundation for the program. Consultant L. Gary Byrd, the Transportation Research Board (TRB) leaders and staff, and Federal Highway Administration (FHWA) leadership were also heavily involved. The research plans were outlined in the National Cooperative Highway Research Program (NCHRP) 20-20 report, entitled *Strategic Highway Research Program Research Plans* (*1*). The Advisory Committee for the Asphalt Study developed these research plans, which were put into play in the research phase.

During the research phase, the program was managed by the SHRP staff as a unit of the National Research Council (NRC); their role in administration and technical guidance of the program cannot be overlooked. The research teams also had an obvious and significant impact on the conduct and results of the research. The roles of some groups, most notably industry and FHWA, were perhaps less significant during this phase than they should have been. These roles – or lack of roles – are explored in Chapter 4.

The field of players expanded significantly as the research phase transitioned into the implementation phase, described in Chapter 5. Industry and the state agencies became increasingly involved. FHWA took the lead in implementing the products of the asphalt research program. When funding at FHWA became a major issue, TRB again assumed a larger role in keeping the program alive through NCHRP research funding and support. Eventually Superpave touched almost every facet of the asphalt community in the United States and abroad as implementation expanded. Again, the players and their evolving roles are explored in later chapters.

CHAPTER 3. PRE-RESEARCH PHASE (1980-1987)

This chapter discusses the time period from 1980-1987. During this time, there was growing support for a national research program to address widespread problems with the highway infrastructure, maintenance and operation. Funding support was obtained and the plans for the research program were developed.

3.1 SEEDS OF THE RESEARCH PROGRAM

The origins of the SHRP Program reach back to the late 1970s and early 1980s. In the late 1970s, after years of neglect, the nation's highway system had deteriorated to a publicly perceptible and technically unacceptable level. Recognizing the need for a revitalized highway program, Congress authorized a four-year, $58 billion federal-aid package for highways in 1982. Financing alone, however, would not solve the problem. It was a well-documented fact that needs far exceeded resources. Eventually, it was realized that innovation, through carefully targeted research, was the key to bridging the gap.

In the early 1980s, many people seriously believed that something was wrong with asphalt pavements. Bob Farris, Commissioner of the Tennessee DOT at the time and later the FHWA Deputy Administrator, may have been one of the first on a national level to state that asphalt "wasn't as sticky as it used to be." Others may have been saying the same thing, but Farris was the first to get the message out to the community.

To track the issue, Farris had his inspectors report directly to him about what was happening. This led to interest at the national level, especially at AASHTO. Farris and others realized that asphalt pavements were not performing as they should. The problems went beyond perception and were real, as evidenced by increasing and premature distress.

AASHTO's Frank Francois and other DOT leaders eventually took up the gavel at the national level and went to visit the refiners. Representatives from the refining industry responded that there was nothing wrong with or different in the product. What was really happening, however, was that the number and types of crude oils that were being used to refine asphalt had dramatically changed as a result of the world wide demand and the oil crisis of the 1970s. Other problems were noted with the inexperience of lab technicians and inspectors, along with the workmanship of some paving contractors.

The DOT leaders also wanted to know if other products or materials were suffering from poor serviceability. In their review, they found out there were technical problems with other materials as well; rebar quality (corrosion) and alkali-silica reactivity were common problems. The quality and serviceability issues with these materials were brought before the AASHTO Standing Committee on Research (SCOR). SCOR was asked to look at this issue, but did not have sufficient funds at its disposal to conduct any type of large-scale, organized study.

The idea of a focused research program was raised, though the actual source is hard to pinpoint. Thomas D. Larson, at the time the Secretary of the Pennsylvania Department of Transportation, and Thomas B. Deen, Executive Director of TRB, had many high level discussions on this issue. Together, they probably deserve credit as the first authors of the idea of a high level research project, in modules or blocks, to deal with these issues and to be responsive directly to the state DOTs. Their initial work led to an outline of a research program.

Lester P. (Les) Lamm, the FHWA Executive Director at the time, was very much in support of the idea of a national research effort. Independently, FHWA agreed that there was enough concern that something needed to be done. Ray Barnhart, then FHWA Administrator, was supporting a broader and bolder research program at FHWA at the same time.

3.1.1 Structuring the Research Program

The normal practice at the time would have been to advertise and award research, with universities being the primary recipients of either grants or contracts with FHWA. Lamm was concerned that a program as significant as this, if given directly to universities, would be extremely difficult to manage. This was because of a combination of tight federal procurement rules and a "hands-off" university culture.

Lamm noted that the universities probably were not going to react positively to very tight schedules and being told in specific detail what the research must accomplish. He suggested that it might be better if AASHTO and TRB looked at a completely different delivery system. Larson and Deen then took it from there and finalized the idea that what was needed was a comprehensive program with multiple emphasis areas, beyond just asphalt.

Interestingly, while history will record the program in six different areas (asphalt, concrete, bridges, maintenance cost-effectiveness, snow and ice control, and long-term pavement performance), the real thrust was towards improving asphalt. "To gain widespread support, we needed to address needs in many other areas," noted Francois.

3.1.2 Funding and Organization

Soon questions arose as to how to fund and manage a program of such magnitude. Nothing of this scale had been done in the highway research arena through the traditional organizational structure.

The idea that surfaced and eventually was implemented was to make the research program similar to the National Cooperative Highway Research Program (NCHRP) with a take-down per state – on a voluntary basis. Credit for this idea probably goes to Arnie Kupferman from the New York State DOT. He suggested that the contribution be mandatory, with the funds going to FHWA and then over to some element in TRB or AASHTO. AASHTO noted that it had no experience or interest in running a program of this magnitude. That led to discussions at TRB. Could they do something like this? Had they ever done something like this? Did they see it as too controversial?

Tom Deen led the examination with the National Academy of Sciences. Eventually, this led to a planning document and framework for a separate entity within NAS. FHWA, through Les Lamm, approved the concept of funding and management of the program, using Federal-aid funds as the source of the program.

3.2 SHRP'S COLORFUL PRECURSORS – THE "BLUE" AND "BROWN" BOOKS

The Strategic Highway Research Program was originally proposed in TRB Special Report 202, *America's Highways: Accelerating the Search for Innovation* (*2*). Published in 1984, the "Blue Book" contained the findings of the Strategic Transportation Research Study (STRS) sponsored by the FHWA and conducted by TRB. The Blue Book documented the need for a concerted research effort to produce major innovations for increasing the productivity and safety of the nation's highway system. It included recommendations for a $150 million, five-year program of research focused on six high-priority areas.

Enthusiastically accepting the recommendations, AASHTO and FWHA led the effort to earmark 0.25 percent of Federal-aid highway funds for SHRP in fiscal years 1987 through 1991. Detailed planning for the research program began in March 1985. Seven contract agencies, each supported by an advisory committee of representatives from the highway community, worked for nearly one year to develop the well-defined plans described in the NCHRP Project 20-20 report, *Strategic Highway Research Program Research Plans* (*1*), more commonly known as the "Brown Book." A timeline of key events preceding the onset of SHRP is shown in Figure 1. Relevant highlights from the Blue and Brown Books are contained in the following sections.

Jan 1983	Jul 1984	May 1984	Oct 1984	Mar 1985	Sep 1985	Jan 1986	Feb 1986	May 1986
STRS Committee Formed	SR 202 "Blue Book" Published	AASHTO Approves SR 202 Recommendations	Office of SHRP Interim Director Established & SHRP Task Force Formed	SHRP Task Force Begins Work (NCHRP 20-20)	SHRP Workshop - Dallas, TX	SHRP Workshop - TRB	SHRP Research Plans Finalized	SHRP "Brown Book" Published

Figure 1 Timeline of Key Events Preceding the Onset of SHRP

3.2.1 The "Blue Book"

The STRS study focused exclusively on public highway facilities and examined transportation research from the vantage point of a "unified industry." This unified industry encompassed highway construction, maintenance and operating activities performed by federal, state, county, city and other operating units of government as well as toll facilities.

The Committee that conducted the study was charged with developing a five-year plan for strategic highway research. Noting that spending on highway research had fallen precipitously from 0.25 percent in 1965 to 0.15 percent in 1982, the obvious question was "Why had a system crucial to the nation's economy and everyday life not been supported by large-scale, long-term research?" The answer to that question was found in the characteristics of the highway industry, its traditional approach to research, and gaps in technology, specifically asphalt technology. These characteristics are summarized as follows (*2*):

- The highway industry was (and remains) dispersed and diverse. Some 38,000 agencies share responsibility for operation of the nation's highways, roads and streets. This decentralization of responsibility increased the sensitivity to local needs and issues as well as to regional topographic, climatic and in situ conditions affecting highway design and maintenance. The private sector, with nearly 65,000 firms producing or supplying materials, was fragmented into thousands of small, local buyers and sellers.
- The financial commitment to highway research lagged far behind the investment in research in other sectors of the economy. High-technology industries, including computers, pharmaceuticals, and aerospace, spent nearly 40 times as much on research as the highway industry. The highway industry even trailed behind low-technology industries, such as building materials, metals and mining, and food and beverage, which spent more than eight times as much on research.
- The complexity of highway construction and maintenance was poorly understood, so research was not considered a high priority. Road-building was familiar and most certainly not glamorous. When budgets were tight, highway research could be easily and indefinitely deferred.
- As shown in Figure 2, the nearly $75 million that the United States spent on highway research in 1982 was disbursed through numerous agencies and programs. In addition to the Highway Planning and Research (HP&R, later called State Planning and Research (SPR)), NCHRP and FHWA programs, at least seven other federal agencies conducted highway-related research.

3.2.1.1 Gaps in Asphalt Technology

Research should be results-oriented in important areas that need improvement. As noted in the previous section, highway research was highly decentralized among all levels of government and many private organizations. No single agency controlled the majority of highway research spending. Also, road quality, safety and environmental consequences were important considerations. These special features of highway research (the need for large-scale integration, and for safety and environmental considerations) combined with the basic requirements of all good research, led the STRS Committee to identify strategic gaps in asphalt research by answering the following questions (*2*):

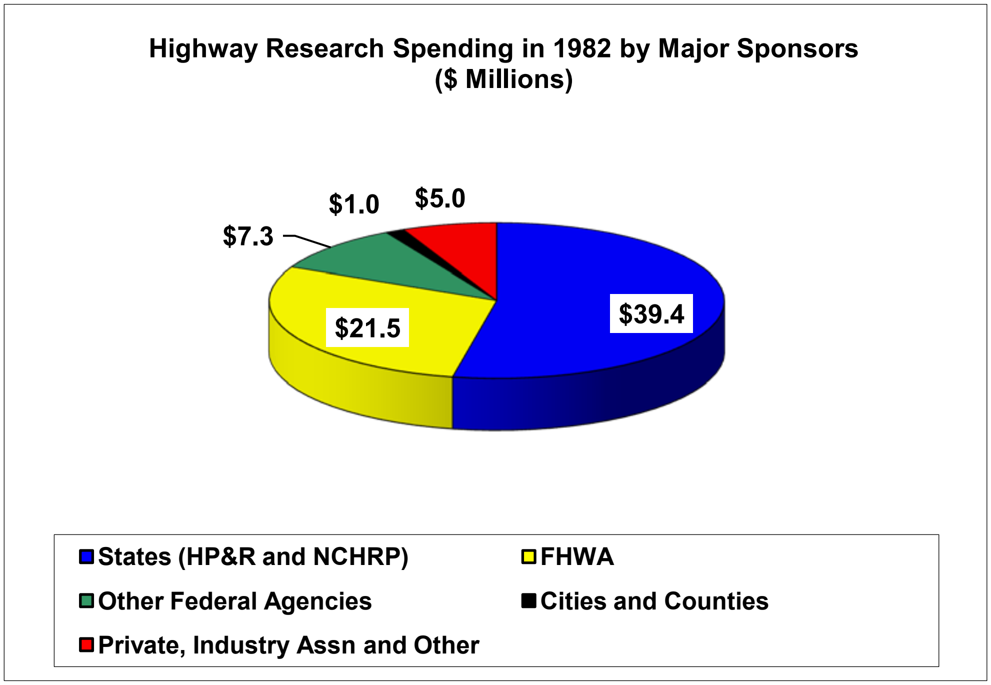


Figure 2 1982 Highway Research Spending (data from SR 202 (2))

Would the research yield big payoffs?
Yes. About $10 billion per year were spent for asphalt pavements, which was about 20 percent of the nation's overall expenditures on highways. A $50 million research project would repay its costs in six months if it achieved only a one percent savings in asphalt pavement costs.

Had the research area been neglected?
Yes. Asphalt generated less than one percent of the annual revenue earned by the US petroleum industry and hence was neglected.

Had important issues been slighted because of institutional or organizational barriers?
Yes. Low-bid procurement discouraged production of higher quality products.

Did the research require effort on a larger scale than could be accommodated by existing programs and institutions?
Yes. Crude oil used in asphalt production came from 200 different sources. It was refined by numerous refineries and processes; combined with numerous additives, cutbacks, and emulsifiers; mixed with a wide variety of aggregates; and constructed according to different designs under a wide variety of conditions.

Did the research require an integrated effort or national approach?
Yes. Part of the failure to see the potential of asphalt research stemmed from the lack of a single clear beneficiary. Until an integrated effort brought together the disparate parts of the process, major fundamental improvements in asphalt would not be found.

Would the research accommodate changes in national policy?
Yes. The Surface Transportation Assistance Act of 1982 increased the funding for most federal highway programs, particularly those that financed resurfacing, rehabilitation, restoration and reconstruction (4-R). These were the areas where the greatest percentages of program funds were spent for pavements, so asphalt would increase in financial importance.

Would the research use or respond to technological changes?
Yes. In short, the oil embargo of the 1970s stimulated the production of asphalt from different crude oils and through different refining processes.

3.2.1.2 Asphalt Program Objectives and Funding

The overall objective of the asphalt research program, as articulated in the Blue Book, was to improve pavement performance through an increased understanding of the chemical and physical properties of asphalt cement in the context of its use in pavement. The research results would be used to develop specifications, tests and construction procedures needed to achieve and control the pavement performance desired. To achieve these objectives, five major steps were envisioned:

1. Define properties of different asphalts,
2. Improve testing and measuring systems,
3. Determine relationships between asphalt cement and pavement performance,
4. Develop improved asphalt binders, and
5. Validate performance in the field.

The work flow and relationships among the various experiments as originally conceived are illustrated in Figure 3.

Elements and relationships of design for asphalt cement experiments

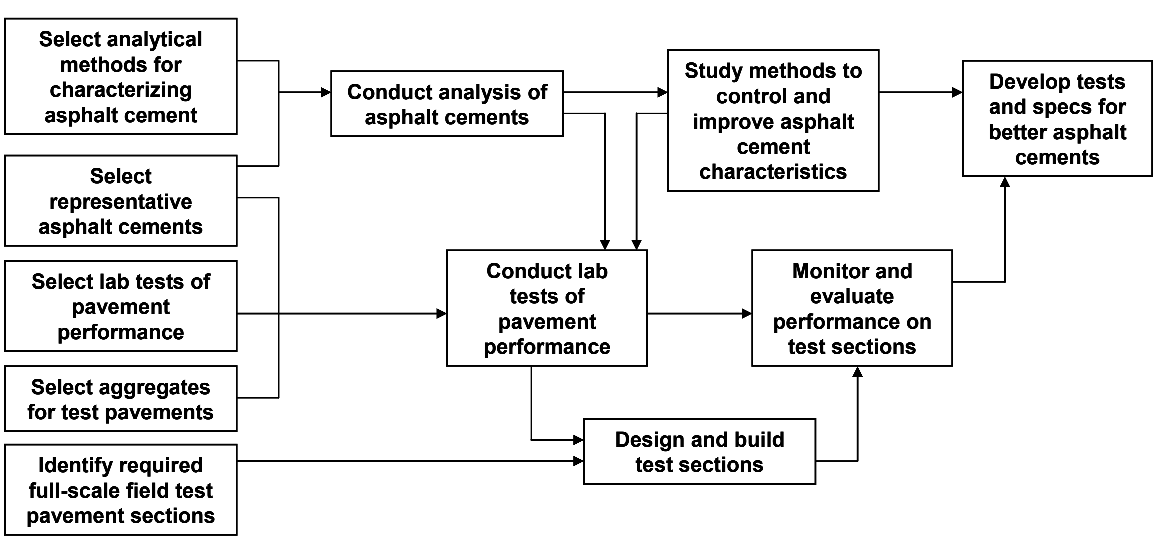


Figure 3 Elements and Relationships of Design for Asphalt Cement Experiments (after SR 202 (*2*))

Projected funding for this five-year, ambitious asphalt research program was estimated at $10 million per year and was allocated as shown in Figure 4.

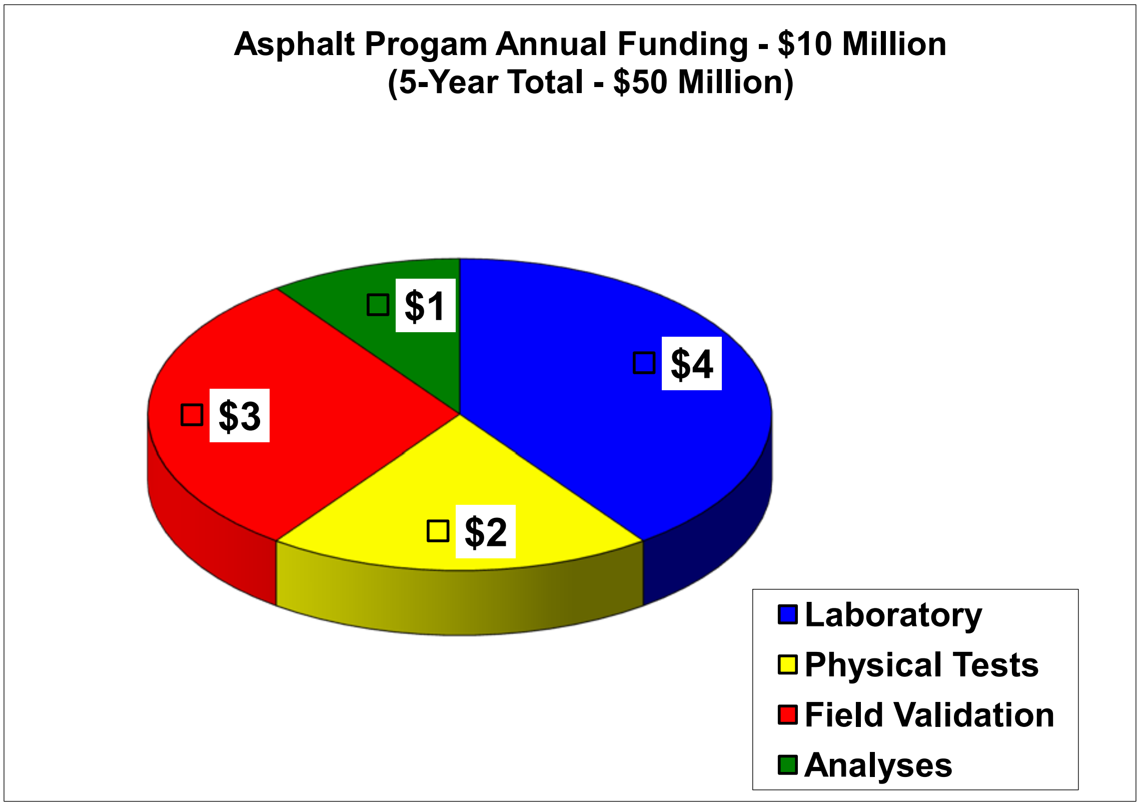


Figure 4 Annual Funding for Asphalt Research Program (after SR 202 (*2*))

3.2.1.3 Institutional Arrangements

The strategic plan presented in the Blue Book was more sharply focused than historical highway research efforts. It concentrated on a few specific goal-oriented areas. The highly focused, product-oriented program would exist for only five years (with the exception of the Long-Term Pavement Performance program). Several alternative institutional arrangements were considered, including the following: an AASHTO task force, the TRB/AASHO Road Test organizational model, a federally chartered agency or special study commission, a modification of NCHRP, an expansion of the Federally Coordinated Program (FCP), the National Bureau of Standards, or an independent research center.

3.2.2 The "Brown Book"

The recommendations to initiate a strategic highway research program were approved by AASHTO's Policy Committee in July 1984. The office of the SHRP Interim Director was established in October 1984 with plans to implement SHRP under the guidance of a special task force. L. Gary Byrd was the interim director, following on from his work with the Blue Book.

Under the auspices of the NCHRP, six contractors were selected by the SHRP Task Force in early 1985 to develop the specific research plans in each technical area. In addition, an advisory committee appointed by the Task Force was created to assist each contractor. The contractor for the Asphalt area was Fred Finn of Austin Research Engineers. Each committee was composed of approximately 30 people and represented a broad range of research organizations, including public and private institutions, academia, and industry. (See Appendix B for the composition of the SHRP Task Force and Asphalt Advisory Committee.)

In September 1985 the preliminary research plans were "previewed" at a National SHRP Workshop held in Dallas, TX. Both US and foreign professionals were invited to the workshop.

The second broad introduction of the developing SHRP effort occurred at the January 1986 Annual Meeting of the Transportation Research Board in Washington, DC. At this meeting, detailed presentations and discussions were held along with a specially developed program to increase the foreign technical community's awareness of the SHRP study.

The individual research plans were finalized by February 1986 and presented to the SHRP Task Force for approval. They were published in NCHRP Report 20-20, *Strategic Highway Research Plans*, (*1*), the "Brown Book," in May 1986.

3.2.2.1 SHRP Organization and Management

SHRP was viewed as two distinct phases of management: a pre-implementation phase that was completed with the publication of the Brown Book and an operational phase that began with the process leading to research contracts. In the operational phase, it was envisioned that there would be nine major organizational units with key responsibilities of each as follows:

National Research Council

SHRP would be administered as a new operating unit of the National Research Council.

SHRP Executive Committee

Comprised of approximately l5 executives or professionals from industry, government and the academic community (with AASHTO, FHWA, and TRB representation in ex-officio capacities), the Executive Committee would provide major policy guidance for the entire program and oversight guidance to the technical program.

SHRP Executive Management Staff

The SHRP executive headquarters would include an Executive Director with two Deputy Directors/Managers, one each for technical operations and administrative matters. This staff would have the responsibility for the day-to-day technical and contract management and monitoring. The SHRP offices were established at 818 Connecticut Avenue NW in Washington, DC, in 1986.

Technical Research Area Staff

This unit would be the operating arm of SHRP management within each technical area. This staff would be responsible for preparation of proposal requests, negotiation of contracts, and direct technical and financial oversight of the program.

Loaned Professionals

"Loaned" professional staff would work within the technical research areas, offering technical expertise that may not have been readily available as employed staff and/or the perspective of the ultimate users of SHRP results.

Data Management Staff

This staff would be responsible for management of all technical data collected within the program. Furthermore, this staff would ensure that the system developed would provide for a permanent data bank for all highway researchers upon the conclusion of SHRP.

Information Transfer

This staff would be responsible for the transfer of technological advances made in the program through the publication and distribution of all reports.

Expert Advisors

The advisory groups would be comprised of a small number of key professionals who would assist SHRP technical staff in proposal evaluation and in the periodic review of the research progress.

Contractor Project Managers

It was anticipated that typical research contracts would be large, multitask technical efforts with funding in excess of $1 million. Also, it was envisioned that the research groups would be teams comprised of several organizations such that the prime contractor would be required to develop a project management team to interact directly with SHRP staff. The contractor project manager would be responsible for technical and financial management of all subcontractor agencies comprising the research "team."

The preceding narrative outlined what was envisioned in the Brown Book. With few exceptions, e.g., no Deputy Directors or Data Management Staff, this is the organizational structure presented in Chapter 4, at least conceptually. Elsewhere, “loaned professionals” became “loaned staff” – personnel from highway agencies in the US and abroad. In large measure, the loaned staff members were there to provide insight from the “user-agency” perspective. The “expert advisors” were expanded to include “Expert Task Groups” in addition to the advisory committees. The role of the Expert Task Groups was to assist in the selection of research contractors and provide somewhat loosely organized, ongoing peer review of the research progress.

3.2.2.2 Major Program Considerations

Other considerations that were thought to enhance the probability of SHRP’s success included the following:

- Broad input: Input from a broad sector – private industry, individual consultants, federal and private research institutes, university researchers and research centers, and consulting engineering companies – was encouraged.
- Coordination with non-SHRP research programs: SHRP was intended to supplement existing research efforts, not replace them.
- User involvement: SHRP should provide the opportunity for involvement by a variety of interest groups including state highway and transportation agencies, private industry and the international community.

- Innovation: Several approaches to increase innovation were considered: allocating funds for unsolicited proposals; contracts with incentives; and private industry participation, particularly where new instrumentation, equipment and materials were anticipated.
- Data management: A data management system was considered critical to the application and use of the knowledge and information developed in SHRP. Types of data considered included the following: technical data from all research areas; literature and textual information; and business management data. It was envisioned that all technical data that supported major findings and conclusions would be preserved so that they could be validated, referenced and expanded upon by subsequent research. Furthermore, it was envisioned that the data would be easily accessible to all interested and qualified users. A relational database to facilitate efficient input, storage, manipulation and access was the goal. The possibility of user fees to offset data system costs was considered.
- Implementation of results: All SHRP research efforts were to devote some portion of project activity to an implementation plan with parallel efforts through the following:

  - FHWA Office of Implementation;
  - Executive summary-type reports and publications, furnished at periodic intervals;
  - Demonstration projects;
  - Private-sector involvement;
  - New test methods in AASHTO and ASTM format;
  - TRB publications and meetings;
  - Technology transfer programs through local agencies;
  - SHRP publications; and
  - National SHRP conferences.

The asphalt program was successful in soliciting input from a broad sector of stakeholders. It did not, however, succeed in developing a data management system that "supported major findings and conclusions … so that they could be validated, referenced and expanded upon by subsequent research." Moreover, the asphalt program data are not "easily accessible to all interested and qualified users," and there is no "relational database to facilitate … manipulation and access."

3.2.2.3 Asphalt Projects, Budgets and Schedule

Detailed planning for the asphalt research program was led by consultants (based on guidance from the Blue Book) with significant input from the AASHTO SHRP Task Force and Asphalt Advisory Committee. There was considerable emphasis on the chemical and physical properties of asphalt cement, despite the general consensus that chemical properties would not be useful for specification purposes. As expected, there were differences of opinion among members of the Advisory Committee as to research topics and corresponding funding allocations. Following three meetings of the Advisory Committee and the National Workshop in September 1985, the program that emerged included five projects and 25 tasks/subtasks, with funding as shown in Table 1 and Figure 5.

In preparing the research plan, the SHRP Task Force, Advisory Committee and consultants identified two ongoing NCHRP projects that would affect the research on asphalt-aggregate mixes: NCHRP Projects 10-26(A), *Performance-Related Specifications for Hot-Mix*

Asphalt, and 9-6(1), *Asphalt-Aggregate Mixture Analysis System (AAMAS)*. The objective of 10-26(A) was to develop performance-related specifications for hot-mix asphalt concrete. The objective of 9-6(1) was to develop an asphalt-aggregate mixture analysis system (AAMAS). These projects were intended to provide an early start for, and to complement, the planned SHRP research.

The objective of each SHRP asphalt project is briefly summarized as follows:

Project 1 ─ Asphalt Properties

The objective of this project was to develop a better understanding of the chemical compositional factors of asphalt that determine its physical properties and influence durability. Understanding the unique properties of recycled asphalt that influence the performance of asphalt-aggregate systems was also important.

Project 2 ─ Performance-Based Testing and Measuring Systems

The overall objective of this project was to develop testing and measuring systems to define the chemical and physical properties of binders and the mechanical properties of asphalt-aggregate systems. Ideally, the standardized tests would be developed in AASHTO and ASTM formats.

Project 3 ─ Models to Predict Pavement Performance

To develop performance-based specifications for asphalt binder and an asphalt-aggregate mix design and analysis system, several steps were necessary: development of performance prediction models using empirical or mechanistic-empirical procedures, calibration of the models to field performance, and evaluation with additional field observation.

Project 4 ─ Performance-Based Specifications and an Asphalt-Aggregate Mix Analysis System

The end-product of this project would be performance-based specifications for asphalt binder and a comprehensive Asphalt-Aggregate Mix Analysis System (AAMAS). The asphalt-aggregate mix analysis would describe laboratory procedures and requirements for the laboratory evaluation of asphalt binders (virgin, recycled or modified) and aggregate to minimize the occurrence of fatigue cracking, low-temperature cracking and permanent deformation. The performance-based specifications would incorporate the findings of Projects 1, 2 and 3.

Project 5 ─ Coordination

The objective of the coordination project was to assure that the combined efforts from each project would remain focused on the overall goals of performance-based specifications and the AAMAS.

Table 1 Proposed Asphalt Projects, Tasks and Budgets (after SHRP Research Plans (*1*))

Project 1 – Asphalt Properties	$ (Million)
1.1 Asphalt Chemical Composition	$ 4.00
1.2 Physical Properties of Asphalt	$ 2.50
1.3 Relationships Between Asphalt Chemical and Physical Properties	$ 3.50
1.4 Relationships of Asphalt Chemical and Physical Properties to Pavement Performance	$ 2.00
1.5 Fundamental Properties of Asphalt-Aggregate Interaction Including Adhesion and Absorption	
1.5a Physiochemical Properties of Asphalt at the Asphalt-Aggregate Interface	$ 2.50
1.5b Physiochemical Properties of Asphalt Used with Absorptive Aggregates	$ 1.50
1.6 Survey of Current Manufacturing Practices	$ 1.00
1.7 Asphalt Modification	$ 5.00
Subtotal	**$ 22.00**
Project 2 – Performance-Based Testing and Measuring Systems	
2.1 Testing and Measuring Systems for Asphalt (with and without asphalt modification)	$ 3.50
2.2 Testing and Measuring for Asphalt-Aggregate Systems (with and without asphalt modification)	
2.2a Fatigue Cracking of Asphalt-Aggregate Systems	$ 2.00
2.2b Permanent Deformation of Asphalt-Aggregate Systems	$ 2.50
2.2c Low-Temperature Cracking of Asphalt-Aggregate Systems	$ 1.50
2.2d Aging of Asphalt-Aggregate Systems	$ 1.00
2.2e Water Sensitivity of Asphalt-Aggregate Systems	$ 1.50
2.3 Relationship of Asphalt Chemical and Physical Properties to Asphalt-Aggregate Mixture Properties	$ 3.00
Subtotal	**$ 15.00**
Project 3 – Pavement Performance Studies	
3.1 Model Development	$ 0.50
3.2 Asphalt Performance Studies	$ 3.00
3.3 Evaluation Procedures for Prediction Models	$ 1.00
Subtotal	**$ 4.50**
Project 4 – Performance-Based Specifications for Asphalt and Asphalt-Aggregate Systems	
4.1 Performance-Based Specifications for Asphalt	$ 3.00
4.2 Performance-Based Specifications for Asphalt-Aggregate Systems (AAMAS)	$ 2.00
Subtotal	**$ 5.00**
Project 5 – Coordination	
5.1 Research Project Coordination	$ 1.00
5.2 Operate Materials Reference Library	$ 1.50
5.3 Experiment Design	$ 0.50
5.4 Economic Considerations	$ 0.10
5.5 Implementation Packages	$ 0.40
Subtotal	**$ 3.50**
Total	**$ 50.0**

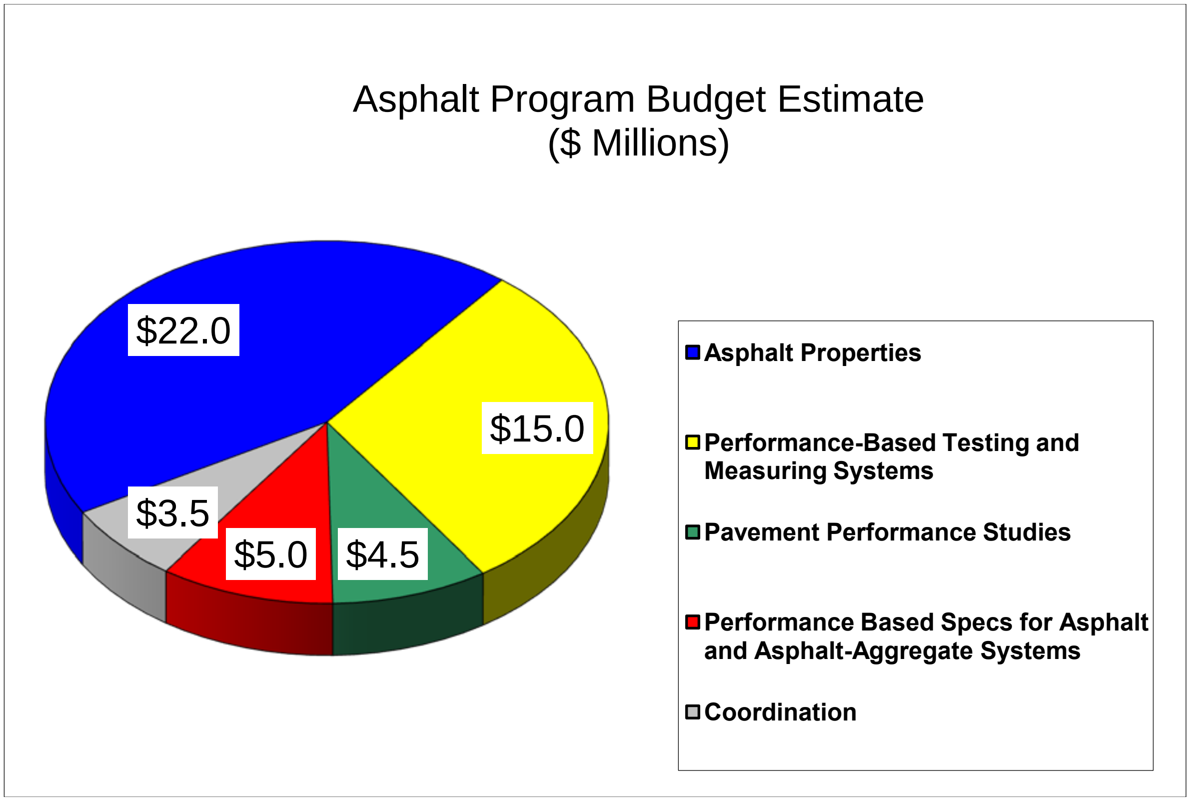


Figure 5 Asphalt Program Budget Estimate (data from SHRP Research Plans (*1*))

The schedule proposed to accomplish the asphalt program research is shown in Figure 6.

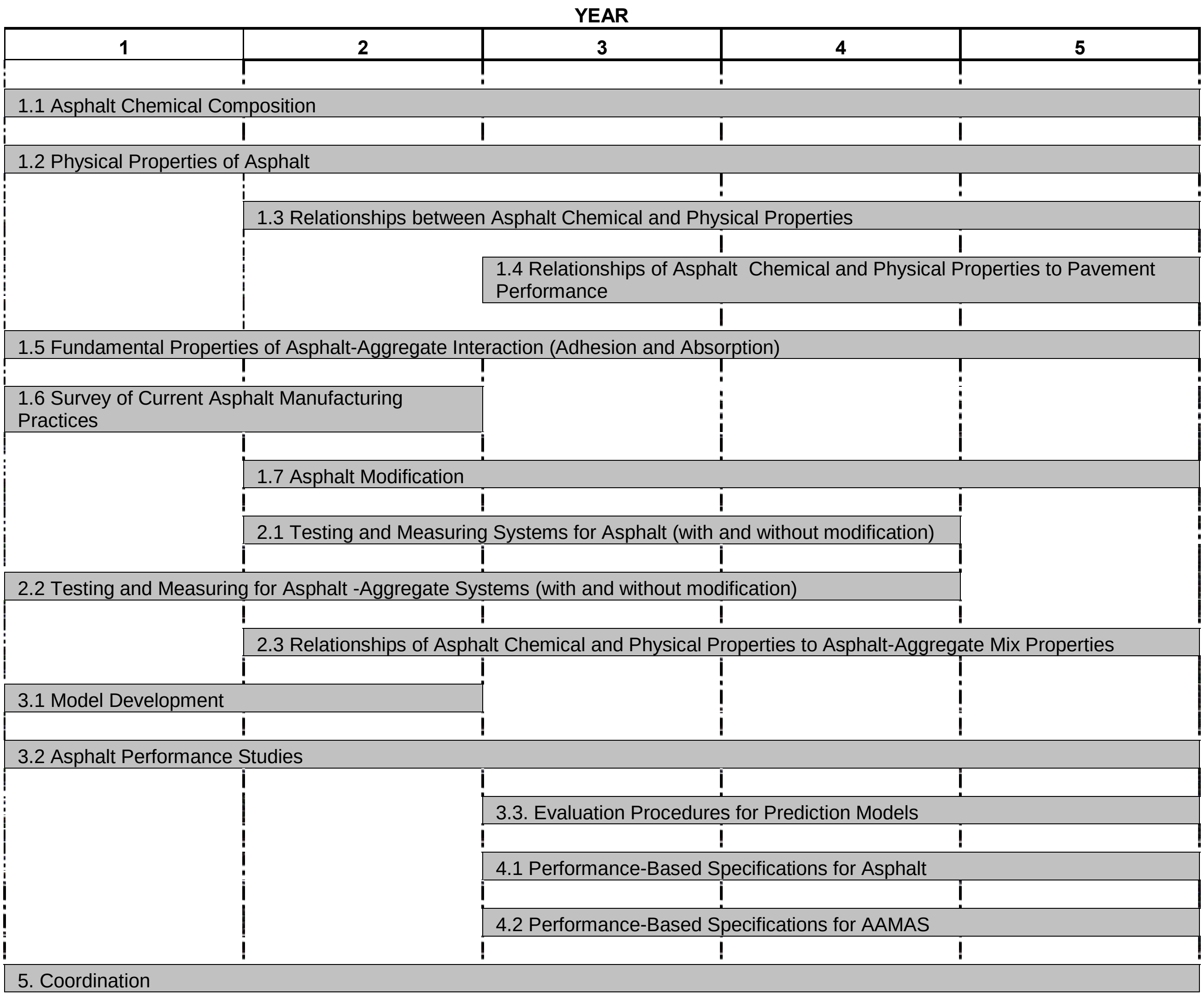


Figure 6 Proposed Schedule for Asphalt Research (after SHRP Research Plans (*1*))

Chapter 4. Research Phase

The research phase began in 1987 after funding for the program was secured. This chapter describes the organizational structure, contracts and other aspects of the research phase.

4.1 ASPHALT PROGRAM STRUCTURE AND STAFFING

Although numerous institutional arrangements were considered in the "Blue" and "Brown" books, SHRP was eventually administered as a new operating unit of the National Research Council with a structure as shown in Figure 7.

The asphalt program staff included a program manager, technical staff and loaned staff. The A-001 contractor, responsible for leadership and coordination of the asphalt contractors, served as an extension of the program staff. The asphalt program technical staff, working closely with the A-001 contractor, was responsible for preparation of the requests for proposals and evaluation of the proposals. Once the contracts were executed, program staff was responsible for technical, financial and administrative oversight of the contracts; the A-001 contractor provided technical oversight in coordination with the program staff. "Loaned staff," both national and international, served on the program staff to provide additional technical expertise and/or the perspective of the ultimate end users of the asphalt program results.

The Asphalt Advisory Committee, with representatives from government, industry and academia, provided strategic guidance. The Expert Task Groups (ETG), similarly constituted, were a resource for technical review of individual asphalt contracts. An ETG was assigned to each major asphalt contract.

4.2 EVOLUTION AND ORGANIZATION OF THE RESEARCH PROGRAM

The SHRP Asphalt Program evolved as it moved from concept to functioning reality. This evolution can be traced from a statement of general objectives in the 1984 recommendations of the Strategic Transportation Research Study (*2*) through more detailed research plans published by TRB in 1986 (*1*); to the Contracting Plan for SHRP Asphalt Research approved by the SHRP Executive Committee in 1987 (detailed in Section 4.2.1); and finally to the 1990 Strategic Plan which was presented at the August 1990 "Mid-course Assessment" meeting held in Denver, CO (*3*).

The emphasis on and need for specification development in the SHRP Asphalt Program originated in the 1984 "Blue Book," which presented the conclusions and recommendations of the STRS project. In that document, the objective of the asphalt research program was stated as follows (*2*):

> *"To improve pavement performance through a research program that will provide increased understanding of the chemical and physical properties of asphalt cements and asphalt concretes. The research results would be used to develop specifications, tests… needed to achieve and control the pavement performance desired."*

This emphasis was reinforced and further defined in the May 1986 "Brown Book." This document stated that a specific constraint or guideline for the asphalt program was as follows (*1*):

> *"…the final product will be performance-based specifications for asphalt, with or without modification, and the development of an asphalt-aggregate mixture analysis system (AAMAS)."*

This document defined the development of the specifications as a task clearly separate from development of the AAMAS.

4.2.1 Contracting Plan

In 1987 the SHRP Executive Committee approved *A Contracting Plan for SHRP Asphalt Research*. The contracting plan combined the multiplicity of tasks identified in the 1986 research plan into a coordinated, manageable structure of six main contracts (which were later expanded to nine, due to the segmentation of the original A-002 and A-003 contracts). This reconfiguration of projects and responsibilities is shown in Table 2. The contracting plan assigned the responsibility for development of the performance-based asphalt binder specification to contract A-001, and the performance-based specification for AAMAS to contract A-006. From the 1987 plan, however, it was clear that the development of the binder specification was the primary objective as is evident from the following (*4*):

> *"In the asphalt area, the original report, America's Highways: Accelerating the Search for Innovation, clearly put the dominant focus on asphalt binders. Subsequent discussions by the AASHTO Task Force, the AASHTO Select Committee on Research and the National Research Council's SHRP Executive Committee have reinforced this initial vision, placing the primary emphasis on research to improve asphalt binders."*

Between 1987 and 1990, nine major research contracts and twelve smaller supporting studies were awarded as shown in Tables 3 and 4 (*5, 6*). In this same time frame, three subtle, but important changes evolved though an ongoing dialogue with those in the highway community who took part in the development, conduct, management and oversight of the program. These included the following:

1) The specification would encompass modified binders as well as unmodified asphalt cements.
2) Accelerated testing was included to validate the binder specification and to improve the AAMAS.
3) The AAMAS would include not only a mix analysis system, but also laboratory mixing and compaction procedures and accelerated performance-related test methods. It was envisioned that the SHRP mix specification development would build upon the NCHRP 9-6(1) work to yield a more robust, well-validated system.

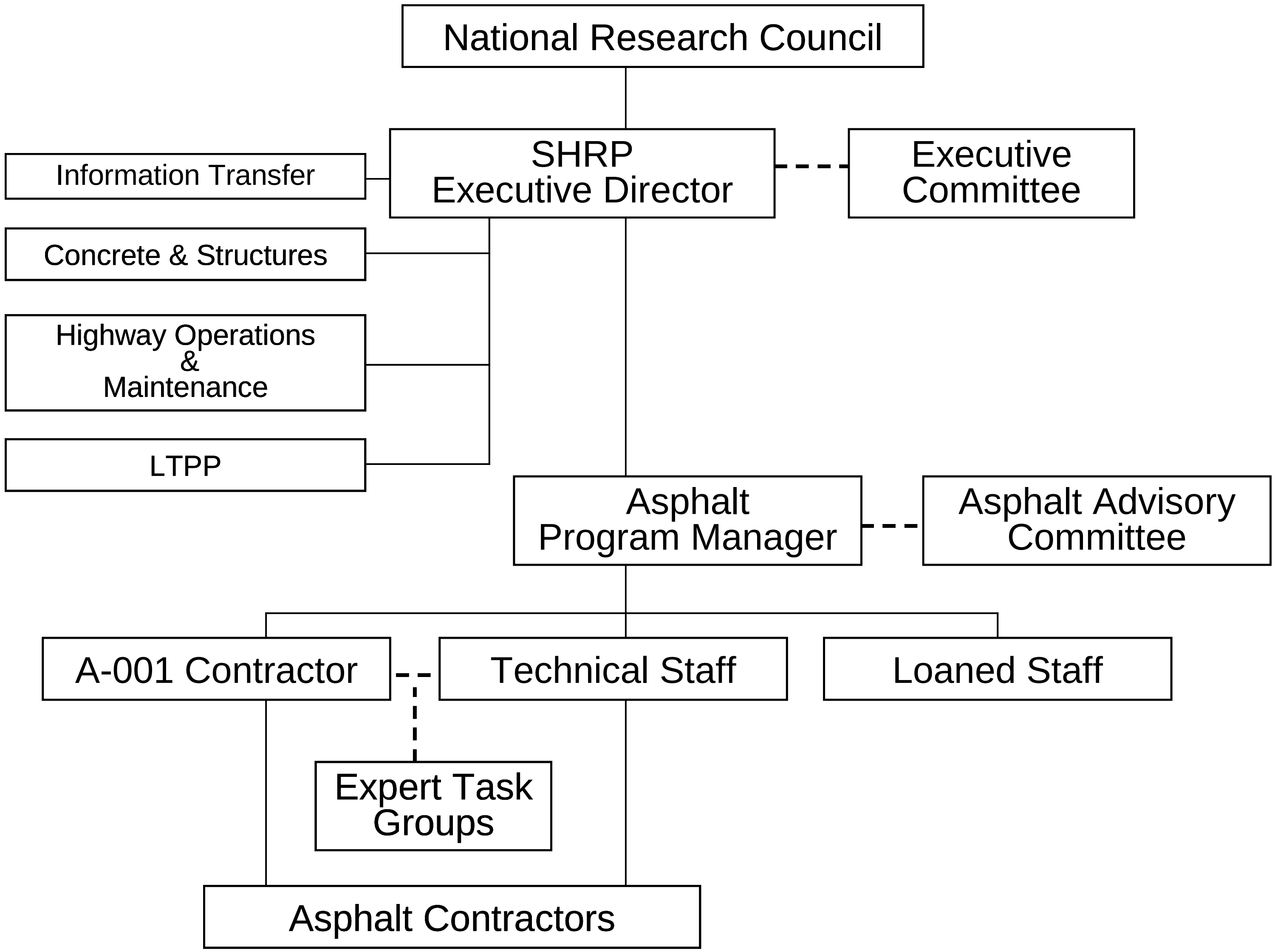


Figure 7 Asphalt Program Structure (dashed lines indicate advisory status)

Table 2 Major Asphalt Research Contracts: Proposed vs. Actual (based on *1* and *4*)

Brown Book – Proposed Research Projects (1986)	Actual Contracts Awarded (1987 – 1993)								
	001	002A	002B	002C	003A	003B	004	005	006
Project 1 – Asphalt Properties									
1.1 Asphalt Chemical Composition	✓								
1.2 Physical Properties of Asphalt		✓							
1.3 Relationships Between Asphalt Chemical and Physical Properties		✓							
1.4 Relationships of Asphalt Chemical and Physical Properties to Pavement Performance		✓			**✓**				
1.5 Fundamental Properties of Asphalt-Aggregate Interaction Including Adhesion and Absorption						✓			
1.5a Physiochemical Properties of Asphalt at the Asphalt-Aggregate Interface						✓			
1.5b Physiochemical Properties of Asphalt Used with Absorptive Aggregates						✓			
1.6 Survey of Current Manufacturing Practices	✓								
1.7 Asphalt Modification							✓		
Project 2 – Performance-Based Testing and Measuring Systems									
2.1 Testing and Measuring Systems for Asphalt (with and without asphalt modification)		✓					**✓**		
2.2 Testing and Measuring for Asphalt-Aggregate Systems (with and without asphalt modification)					✓		**✓**		
2.2a Fatigue Cracking of Asphalt-Aggregate Systems					**✓**				
2.2b Permanent Deformation of Asphalt-Aggregate Systems					**✓**				
2.2c Low-Temperature Cracking of Asphalt-Aggregate Systems					**✓**				
2.2d Aging of Asphalt-Aggregate Systems					**✓**				
2.2e Water Sensitivity of Asphalt-Aggregate Systems					**✓**				
2.3 Relationship of Asphalt Chemical and Physical Properties to Asphalt-Aggregate Mix Properties					**✓**				
Project 3 – Pavement Performance Studies									
3.1 Model Development					✓			**✓**	
3.2 Asphalt Performance Studies					✓			**✓**	
3.3 Evaluation Procedures for Prediction Models								**✓**	
Project 4 – Performance-Based Specifications for Asphalt and Asphalt-Aggregate Systems									
4.1 Performance-Based Specifications for Asphalt	**✓**	✓							
4.2 Performance-Based Specifications for Asphalt-Aggregate Systems (AAMAS)	**✓**				✓				✓
Project 5 – Coordination									
5.1 Research Project Coordination	✓								
5.2 Operate Materials Reference Library	✓								
5.3 Experiment Design	✓								
5.4 Economic Considerations	✓								
5.5 Implementation Packages	✓								

For tasks with more than one "✓," bold denotes primary responsibility.

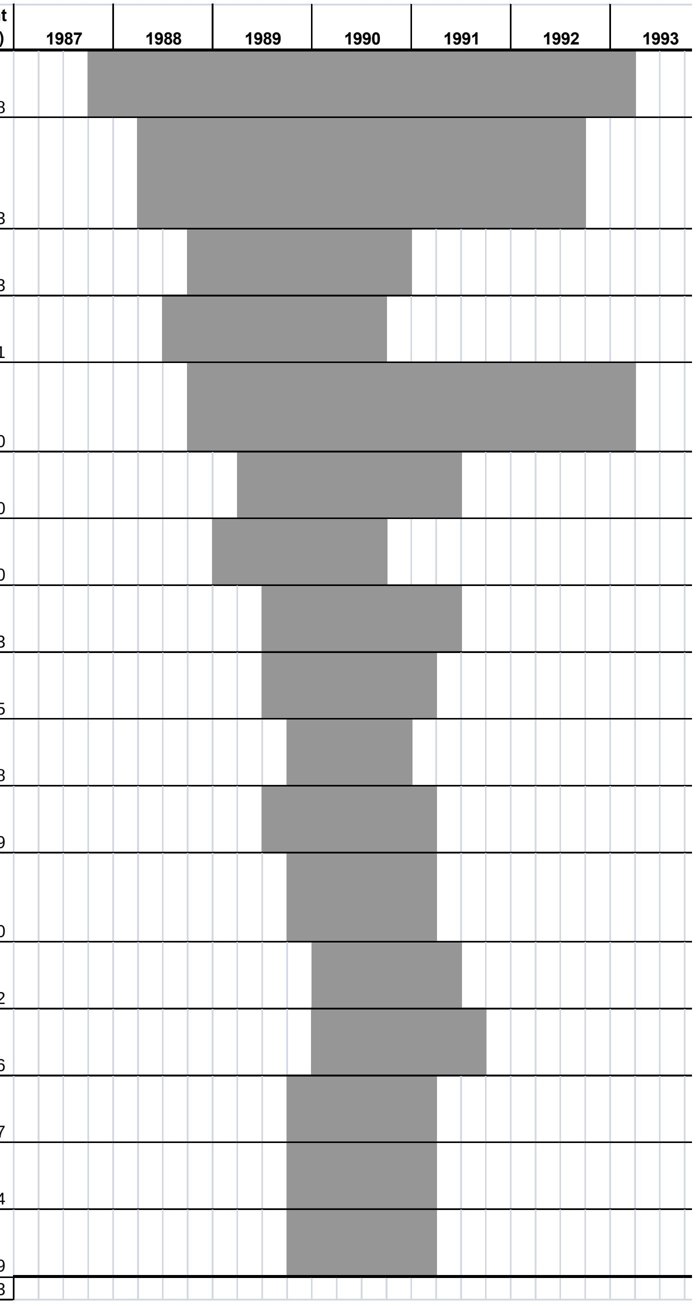
Table 3 Major Asphalt Contracts (*4*)

Contract Number and Name	Contractor/Location	Amount ($1,000)	1987 Jan-Mar	1987 Apr-Jun	1987 Jul-Sep	1987 Oct-Dec	1988 Jan-Mar	1988 Apr-Jun	1988 Jul-Sep	1988 Oct-Dec	1989 Jan-Mar	1989 Apr-Jun	1989 Jul-Sep	1989 Oct-Dec	1990 Jan-Mar	1990 Apr-Jun	1990 Jul-Sep	1990 Oct-Dec	1991 Jan-Mar	1991 Apr-Jun	1991 Jul-Sep	1991 Oct-Dec	1992 Jan-Mar	1992 Apr-Jun	1992 Jul-Sep	1992 Oct-Dec	1993 Jan-Mar	1993 Apr-Jun	1993 Jul-Sep	1993 Oct-Dec
A-001: Asphalt Experimental Design, Coordination, and Control of Materials	University of Texas at Austin, Austin, TX Tom Kennedy, PI	$6,188				■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■			
A-002A: Binder Characterization and Evaluation	Western Research Institute, Laramie, WY Claine Peterson, PI Ray Roberston and Dave Anderson, Co-PI	$9,033						■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					
A-002B: Novel Approaches for Investigating Asphalt Binders	University of Southern California Costas Synolakis and Victor Chang, Co-PI	$893								■	■	■	■	■	■	■	■	■												
A-002C: Nuclear Magnetic Resonance (NMR) Investigation of Asphalt	Montanta State University, Bozeman, MT Wyn Jennings, PI	$601							■	■	■	■	■	■	■	■	■													
A-003A: Performance-Related Testing and Measuring of Asphalt-Aggregate Interactions and Mixtures	University of California-Berkeley Carl Monismith, PI Fred Finn and Gary Hicks, Co-PI	$9,500								■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■			
A-003B: Fundamental Properties of Asphalt-Aggregate Interaction	Auburn University, Auburn, AL Christine Curtis, PI	$3,000								■	■	■	■	■	■	■	■	■	■	■	■	■								
A-004: Asphalt Modification	Southwestern Labs, Houston, TX David Rowlett, PI	$3,363									■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■			
A-005: Performance Models and Validation of Test Results	Texas A&M Research Foundation, College Station, TX Robert Lytton, PI Rey Roque, Co-PI	$3,249													■	■	■	■	■	■	■	■	■	■	■	■				
A-006: Performance-Based Specifications for Asphalt-Aggregate Mixtures **	University of Nevada at Reno, Reno, NV PI, Chuck Hughes	$895															■	■	■	■	■	■	■							
		$36,722																												

** A-006 subsequently folded into A-001 Contract following 1990 "Midcourse Assessment"

Table 4 AIIR (Asphalt, Independent, Innovative Research) Supporting Asphalt Contracts (*4*)

Contract Number and Name	Contractor/Location	Amount ($1,000)
A-001: Asphalt Experimental Design, Coordination, and Control of Materials	University of Texas at Austin, Austin, TX Tom Kennedy, PI	$6,188
A-002A: Binder Characterization and Evaluation	Western Research Institute, Laramie, WY Claine Peterson, PI Ray Roberston and Dave Anderson, Co-PI	$9,033
A-002B: Novel Approaches for Investigating Asphalt Binders	University of Southern California Costas Synolakis and Victor Chang, Co-PI	$893
A-002C: Nuclear Magnetic Resonance (NMR) Investigation of Asphalt	Montanta State University, Bozeman, MT Wyn Jennings, PI	$601
A-003A: Performance-Related Testing and Measuring of Asphalt-Aggregate Interactions and Mixtures	University of California-Berkeley Carl Monismith, PI Fred Finn and Gary Hicks, Co-PI	$9,500
AIIR-01: Asphalt Characterization by Supercritical Fluid Chromatography/Fourier Transorm Infrared Micospectometry	University of Connecticut, Storrs, CT J Stevens, PI	$230
AIIR-02: Air Permeability of Asphaltic Materials, and Gas Permeability and Thermal Oxidative Stability Studies on Asphalt Materials using Electrodynamic Balance	Research Triangle Institute Research Triangle Park, NC ??? PI	$250
AIIR-04: Fluorometric Characterization of Asphalts	Pennsylvania State University, University Park, PA A Davis and G Mitchell, Co-PI	$143
AIIR-05: Rheological Studies of Asphalts Correlations with Structural Parameters	Pennsylvania State University, University Park, PA I Harrison, PI	$135
AIIR-06: Asphalt Binder Characterization and Evaluation: Thermal Chromatography - Mass Spectrometry	David Sarnoff Research, Princeton, NJ B Benz, PI	$88
AIIR-07: Surface Analysis by Laser Ionization of the Asphalt-Aggregate Bond	SRI International, Menlo Park, CA T Mills, PI	$219
AIIR-09: Significance of Intermediate Principal Stress, Principal Plane Rotation, and Evaluation of Loading Spectra on Fracture and Permanent Deformation of Asphalt Concrete	Texas A&M Research Foundation, College Station, TX W Crockford, PI	$180
AIIR-10: Evaluation of Donor-Acceptor Properties of Asphalt and Aggregate Materials and Relationship to Asphalt Performance	David Sarnoff Research, Princeton, NJ M Labib, PI	$152
AIIR-11: Fundamentals of the Asphalt-Aggregate Bond	SRI International, Menlo Park, CA D Ross, PI	$246
AIIR-12: Innovative Techniques to Distinguish Performance of Asphalt-Aggregate Mixtures	CTL International, Inc. Columbus, OH O Abdulshafi, PI	$177
AIIR-13: Microscopial Analysis of Asphalt-Aggregate Mixtures Related to Pavement Performance	The Danish National Road Laboratory, Roskilde, Denmark K Erickson, PI	$184
AIIR-14: Advanced High Performance with Permeation Chromatography Methodology	Montanta State University, Bozeman, MT W Jennings, PI	$179
		$2,183



To achieve the research goals, the program was envisioned to progress in four phases as follows and as shown in Figure 8:

1. Conceptualization - The physicochemical properties of asphalt binders and mechanical/structural properties of asphalt-aggregate mixes that affect pavement performance were to be identified.
2. Definition - The effects of binder properties were to be validated in asphalt-aggregate mixes through laboratory testing and, to a lesser degree, through accelerated pavement testing. Concurrently, standardized test methods to support the binder specification and AAMAS were to be developed.
3. Validation – Field performance data were to be used to validate binder and mix properties that affect pavement performance.
4. Adoption – Final recommendations for the binder and mix specifications would be made and implementation would begin.

As articulated in the 1990 strategic plan, the scope and objectives of the major contracts were as follows (*4*):

Contract A-002A (Binder Characterization and Evaluation): Identify the chemical and physical properties of asphalt binder believed to influence the performance of asphalt-aggregate pavement systems. Refine into test methods those chemical and physical characterization processes that appear to offer the most practical basis for specification testing in terms of the following: correlation between binder properties, mixture performance and pavement performance established by contracts A-003A and A-005; reliability; cost; ease of use; and other features of the tests themselves.

Contract A-003A (Performance-Related Testing and Measuring of Asphalt-Aggregate Interactions and Mixtures): Validate in asphalt-aggregate mixtures the candidate relationships identified in contract A-002A (and to a lesser extent, A-003B and A-004) between the physical and chemical properties of asphalt binder and asphalt pavement performance (first-stage validation). Develop standardized, accelerated test methods for asphalt-aggregate mixtures that may be employed in a mixture analysis system to support a performance-based specification for mixtures.

Contract A-003B (Fundamental Properties of Asphalt-Aggregate Interaction): Develop a fundamental understanding of the chemistry of the asphalt-aggregate bond and how it affects adhesion and water sensitivity. Develop a fundamental understanding of the mechanical and chemical basis of asphalt absorption into highly porous aggregates. Prepare reliable, practical test methods that measure asphalt-aggregate adhesion, water sensitivity and absorption and estimate their effects on pavement performance.

Contract A-004 (Asphalt Modification): Adapt as necessary performance-related test methods for binders and mixtures to permit their use with the full range of modified systems. Explore innovative refinery processes to enhance the performance of modified asphalt binders. Develop a modifier evaluation protocol to permit evaluation and selection of modified binder systems that remedy specific pavement performance gaps.

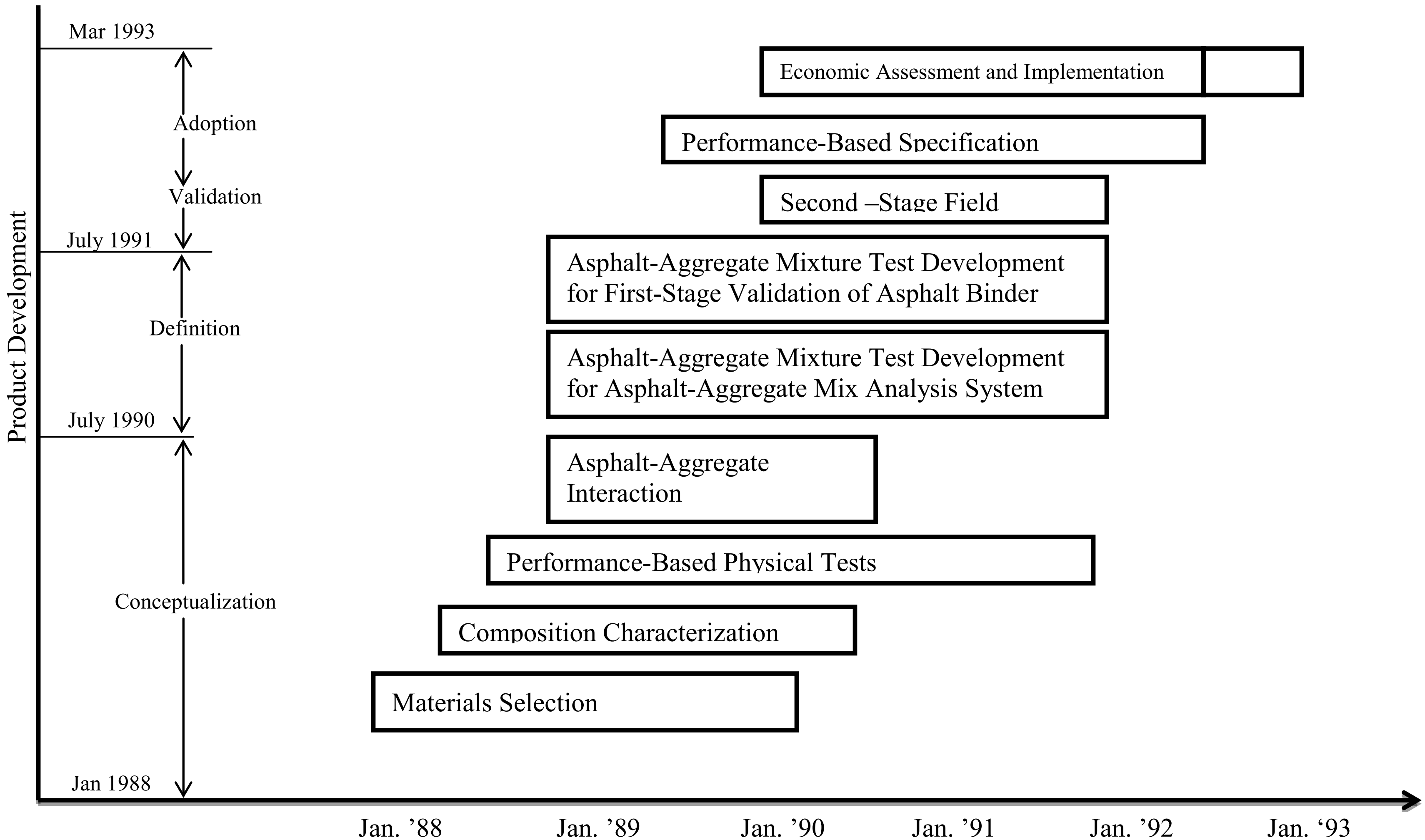


Figure 8 Strategy to Achieve Key Products (after *5*)

Contract A-005 (Performance Models and Validation of Test Results): Validate relationships between asphalt binder and asphalt-aggregate mixture properties and pavement performance (second-stage validation). On the basis of documented field performance data, establish criteria, limits and requirements that may be used for asphalt binder and asphalt-aggregate mixture specifications. Develop performance prediction models incorporating the properties of asphalt binders and asphalt-aggregate mixtures

Contracts A-001 (Asphalt Experimental Design, Coordination and Control of Materials) and A-006 (Performance-Based Specifications for Asphalt-Aggregate Mixtures): Prepare model, performance-based specifications for asphalt binders and asphalt-aggregate mixtures, respectively, using the validated results of contracts A-002A, A-003A, A-003B, A-004 and A-005. Furthermore, the A-001 contractor was responsible for technical direction, leadership and coordination of the asphalt program.

4.2.2 Materials Reference Library

The magnitude and breadth of the asphalt program required major endeavors through broad and complex research efforts. For the research to be both meaningful and effective, all the asphalt researchers would have to use the same materials. Accordingly, the A-001 contractor developed and operated the Materials Reference Library (MRL) containing sufficient quantities of asphalts and aggregates for use by the asphalt researchers through the entire 5½-year program. (*4*)

In fact, this library of materials is still in existence and use today (although it has been moved from its original location in Austin, Texas, to Reno, Nevada). Researchers still request samples of the original SHRP asphalts for various projects. This allows current researchers to build on the work done during and since SHRP. Other materials (aggregates, sub grade materials, mixtures, etc.) from LTPP (Long-Term Pavement Performance) projects across the country are also stored in the MRL and available to researchers upon request and with FHWA approval.

4.2.2.1 Asphalt Selection Process

The basic premise of the selection process for the asphalts was that the performance of asphalt pavements is directly influenced by the physicochemical properties of the asphalt cement. Thus, asphalt cements were deliberately chosen to create an MRL containing currently available asphalt cements representing a wide range of field performance histories, crude oil sources, refinery practices, and physical and chemical properties. Thirty-two asphalt cements were selected, sampled and stored in the MRL. The geographic distribution of the refineries from which asphalts were sampled is shown in Figure 9.

Eight of the asphalts were selected as having sufficiently diverse performance histories, chemical and physical properties to warrant their being designated as the core or common asphalts in the asphalt program. The core asphalts were to be tested in every experiment in the asphalt program to permit a systematic analysis and correlation of the data obtained in the various contracts and parts of the program.

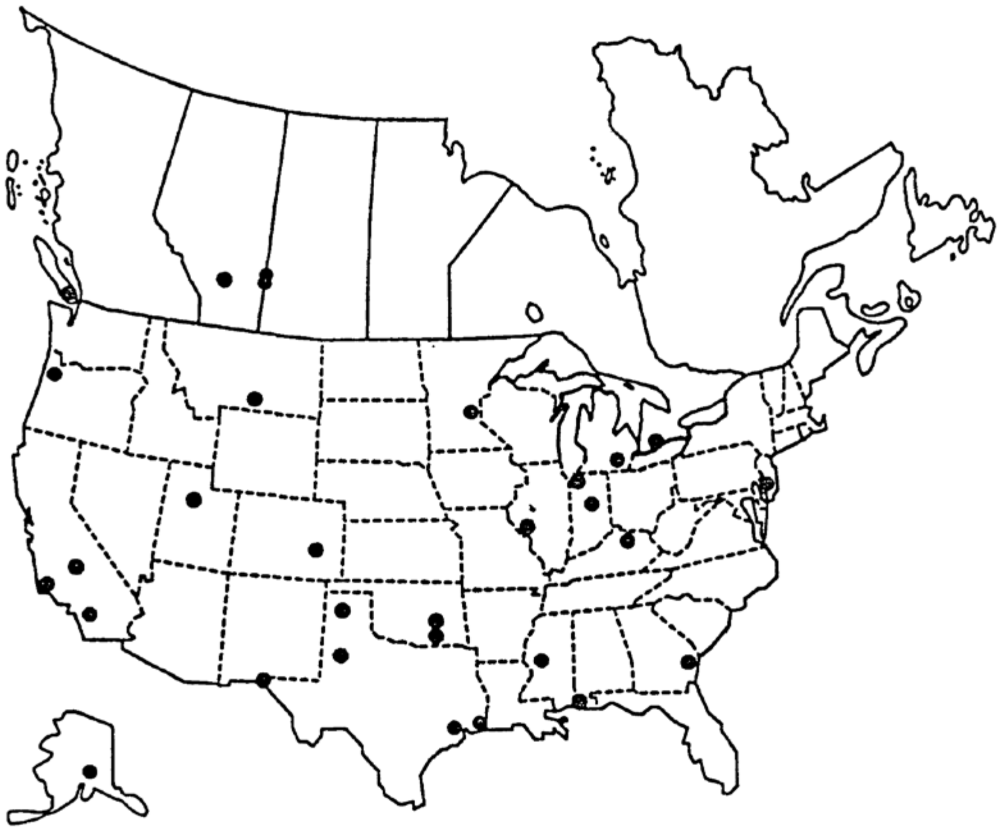


Figure 9 Geographical distribution of asphalt sampled for the Materials Reference Library

4.2.2.2 Aggregate Selection Process

A similar approach was employed in the selection of the aggregates. The aggregates were chosen based on known chemical, physical, geologic and petrographic properties as these properties related to perceived performance in asphalt-aggregate mixes. The geographic distribution of the eleven aggregates selected is shown in Figure 10.

Figure 10 Geographical distribution of aggregates sampled for the Materials Reference Library

4.2.3 Validation and Analysis of Research Data

A central problem of the asphalt research program was how best to translate the large volumes of research results generated by more than twenty contractors into a coherent set of performance-based specifications. The following narrative outlines the validation strategy employed.

4.2.3.1 Overview of Validation

The process of validation was viewed as a pyramid (Figure 11) with the validated, performance-based specifications at the pinnacle. Individual experiments conducted in each of the contracts form the base. These experiments were to be statistically designed.

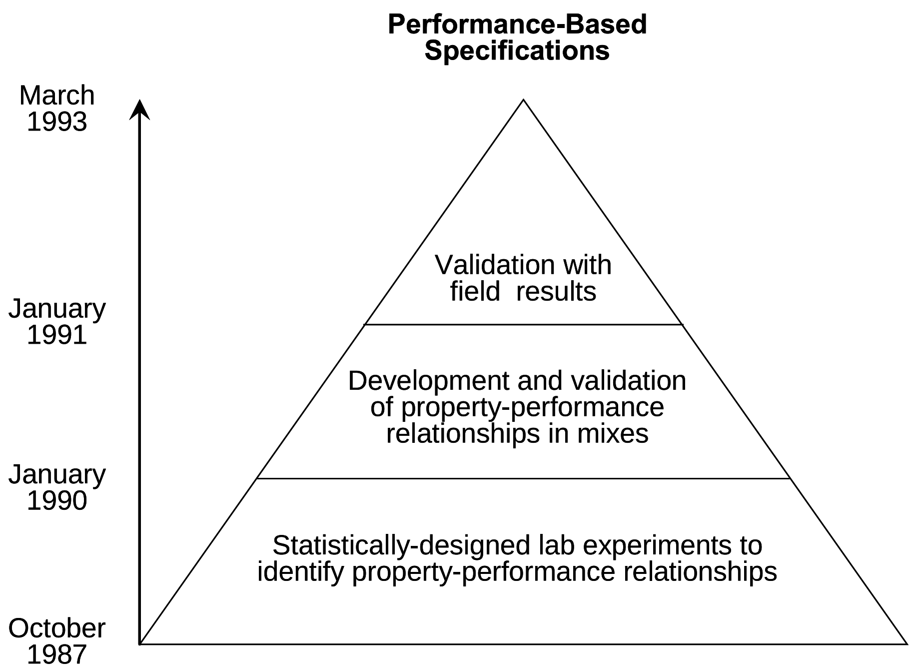


Figure 11 Data treatment pyramid (after *5*)

Higher up on the pyramid, research results from all the different experiments in the program were to be evaluated and combined in different ways to select a consistent set of relationships between material properties and performance that may be a suitable basis for specifications.

The highest level of the pyramid was the validation process that would occur in two stages in contracts A-003A and A-005. Promising relationships selected on the basis of laboratory test results were to be tested against field data. Ideally, this validation process would be conducted with well-controlled, long-term field experiments such as those of the LTPP Specific Pavement Study (SPS) series. The tight schedule for the asphalt research program, however, precluded complete reliance upon a long-term program such as LTPP. Rather, the best-available information, running the gamut from reliable data from controlled field experiments to personal observations by experienced engineers, would have to be identified, assessed and combined in an accelerated validation process in order to reach the pinnacle of the pyramid within the 5½-year program.

Each level of the pyramid would require a different set of analytical techniques and assumptions. At each stage in the process, a different mix of deductive and inductive reasoning would be needed.

The successful development of performance-based specifications would require the validation of binder and mix properties identified as important determinants of pavement performance.

4.2.3.2 First- and Second-Stage Validation

Validation of the asphalt program results would be a two-stage process coordinated between contracts A-003A and A-005. The first stage (contract A-003A) would confirm that variation of asphalt binder properties identified as probable, significant determinants of pavement performance caused reasonable, meaningful changes in the relevant performance characteristics of asphalt-aggregate mixes.

The second stage of the validation (Contract A-005) would establish the degree of correlation between the asphalt binder properties shown to significantly affect performance-related characteristics of asphalt-aggregate mixes and pavement performance, and provide data upon which to set the specification limits for the relevant properties selected to control performance.

The basis for a successful validation process would be the use of statistically sound experiment designs. All major contractors would be required to establish statistically sound designs for all major experiments. Additionally, for the asphalt program to be successful, there had to be a mechanism to allow all the researchers to merge, correlate and draw statistically valid inferences from the data collected from the various studies.

These requirements would be satisfied in two ways. First, all researchers participating in the program would employ the same materials, essentially the 32 asphalt cements and 11 aggregates contained in the MRL. Inherent in the MRL selection process was the assumption that the 32 MRL asphalts spanned the range of performance expected from the full set of asphalts available then and in the future in the United States and Canada.

Second, the research studies in the asphalt program would be organized as experiments selected to test hypotheses and accomplished according to basic statistical procedures and sound experiment designs. The experiments would be designed to validate relationships among test variables, to calibrate and validate test procedures and equipment, and to establish specification variables or criteria.

The validation at the core of the asphalt program would be founded upon a series of well-designed experiments. These experiments were expected to identify important relationships between asphalt binder properties and predicted field performance and to provide the first-stage laboratory validation that these relationships translate into significant variation in the corresponding properties of asphalt-aggregate mixes.

The more difficult question was how to demonstrate that the binder property was truly predictive of field performance. The first-stage validation would show only that the binder property was correlated with a mix property. The second stage of the validation process would consist of a mathematical correlation of the candidate binder and mix properties with performance data gathered from both full-scale pavement test facilities such as the FHWA Accelerated Load Facility (ALF) and in situ field pavements studies, typified by the SHRP LTPP General and Specific Pavement Study (GPS and SPS) pavement sections.

The first stage of the validation process was looked upon as an inductive process since it would not provide conclusive grounds for the truth of the conclusion that relationships existed between binder properties and pavement performance, but rather afforded some support for it. The second stage of the process, however, would be a deductive process in that it would provide conclusive grounds for this conclusion. It would rely upon the correlation of binder and mix properties with actual field performance to demonstrate the soundness of the inferred relationships between properties and performance.

In practical terms, the ultimate predictive value of the binder or mix property would be tempered by several factors including the number of field pavement sections utilized in the validation and the degree to which the field pavement sections represented controlled experiments. Performance data from LTPP SPS sections was preferable to GPS section data since the SPS sections were being constructed as controlled experiments. Both were preferable to data gathered from a random assembly of uncontrolled field pavement sections.

It was acknowledged, however, that if insufficient field data were available from existing pavements, performance data from other sources would have to be employed, e.g. historical projects that were extensively described in the literature and/or interviews with experienced materials engineers who could provide information concerning asphalt properties and pavement performance, etc.

In summary, the validation in the laboratory of candidate properties for incorporation in performance-based specifications would be principally an inductive process. It would be aided by the existence of complete data sets from well-designed, controlled experiments, but could not conclusively prove perceived relationships to pavement performance.

By contrast, the conclusive selection of a final suite of properties actually used in the specifications and their limits would require a deductive validation process that would likely employ a mix of statistical data treatment, judgment, interpretation and intuition to compensate for a lack of long-term performance analysis and the possible need to employ incomplete or poor quality performance data. In the end, this approach worked reasonably well for the stage 1 validation of the binder specification. It was less successful for the mix specification. In that case, the sequencing of the contracts, time constraints and lack of performance data (from controlled field experiments or full-scale accelerated testing) made the completion of the validation process virtually impossible.

Flow charts illustrating the integration of work products from the various contracts to develop the performance-based specifications are shown in Figures 12 and 13.

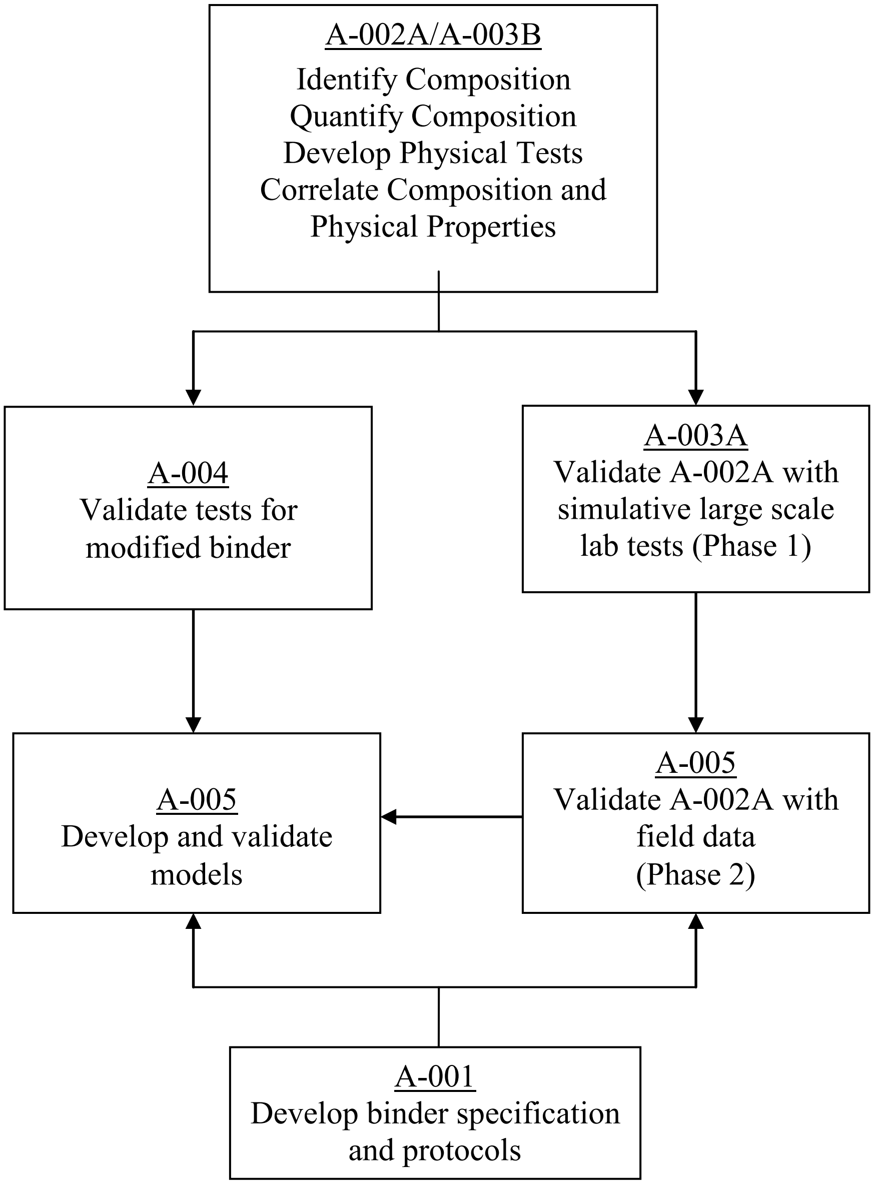


Figure 12 Strategy to achieve performance-based asphalt binder specification (*5*)

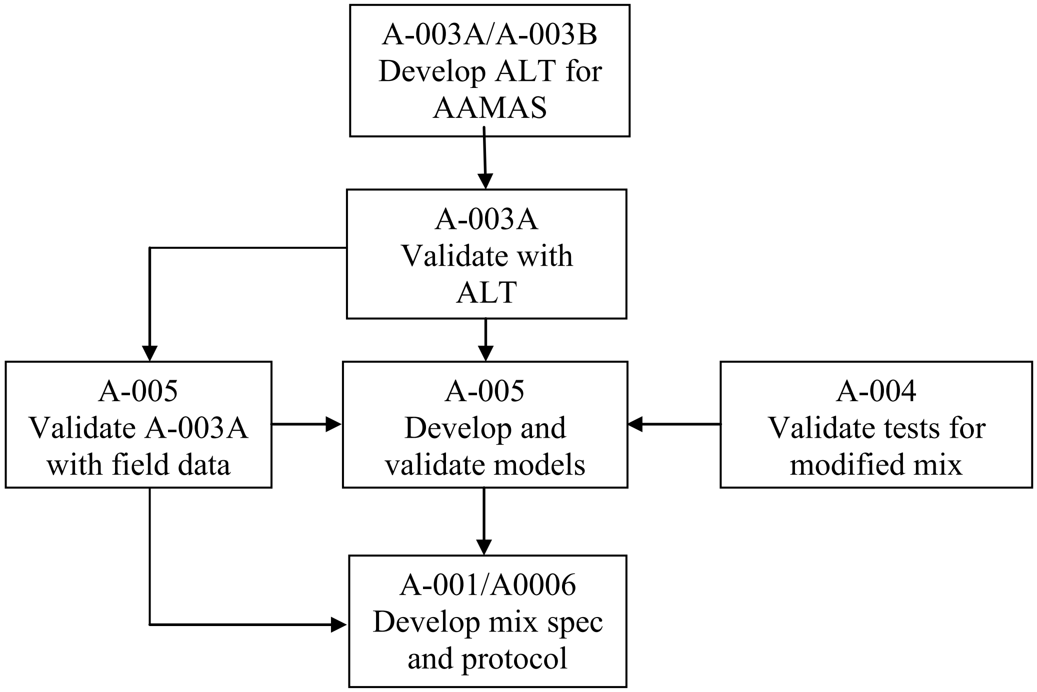


Figure 13 Strategy to achieve performance-based asphalt-aggregate mix specification (*5*)

Note: ALT = Accelerated Laboratory Tests

4.2.4 Mid-course Assessment

At the August 1990 "Mid-course Assessment" meeting (*3*), SHRP Executive Director Damian Kulash asked the 400+ attendees – representatives of state highway agencies, industry, and research organizations – to help SHRP look with fresh eyes at each part of the program and to decide where best to concentrate efforts to get the most out of the research. Three workshops were held for the asphalt program: binder specification, mix specification and validation. For the binder and mix specification workshops, participants considered the following: hard products, gaps in product development, top priority research, potential economic impacts, and routes and barriers to implementation. For the validation techniques, workshop participants considered the methodology, sources of field data, schedule and alternate approaches.

Some of the key recommendations from the asphalt workshops, summarized herein, are included for several reasons. They allow one to compare and contrast what was envisioned in 1990 with what finally emerged in 1993. Also, they set the stage for implementation and the post-SHRP asphalt research agenda, as stated in the report on the mid-course assessment (*3*).

- *The emphasis in the asphalt research should continue to be on identification of the underlying chemical basis for permanent deformation, fatigue cracking, low-temperature cracking, moisture sensitivity, and aging.*

- *Tests of physical properties referenced in the binder specification should have a sound correlation with the underlying chemical properties of the asphalt. There should be a balance between chemical and physical tests.*
- *Consideration should be given to the inclusion of traffic levels in the binder specification.*
- *The user-producer group concept was proposed as part of the implementation process in the pre-1993 period.*
- *While an aggregate specification was beyond the scope of the program, exploration of the effects of the surface chemistry and porosity of the aggregate on adhesion and moisture sensitivity should receive continued emphasis.*
- *The Asphalt-Aggregate Mix Analysis System (AAMAS) and specification methodology should be kept as simple and practical as possible.*
- *AAMAS would require a link between lab mix design and plant production.*
- *Field tests for quality assurance and quality control should be identified or developed.*
- *The effect of large aggregates should be investigated thoroughly in relation to the development of the AAMAS and the mix specification, particularly in relation to the accelerated laboratory tests being conducted under contract A-003A.*
- *Provisions to assure the workability of the mix should be included in the specification.*
- *SHRP should consider the operational impact of new specifications on both centralized and decentralized design practices.*
- *For the second-stage validation, the A-005 contractor should consider the following sources of data: state projects and test tracks; Asphalt Institute field studies; FHWA and Department of Defense experimental projects; and accelerated loading facilities.*
- *The adoption into practice of the performance-based binder specification and the mix specification would have significant economic impact on the state highway agencies, hot-mix producers and contractors, asphalt refiners, and other components of the industry, in terms of capital equipment purchases, new personnel and training requirements, changes in operations, changes in crude oil sources, etc. Serious efforts to quantify these impacts to aid implementation of the specifications should begin immediately.*
- *A comprehensive training program must be launched as early as possible.*

To ensure compatibility between the binder and mix specifications, the A-006 contract responsibilities were folded into the A-001 contract shortly after the "Mid-course Assessment."

The following sections include more detailed discussions of the individual contracts including hypotheses, people and products.

4.3 BINDER-RELATED RESEARCH

Much of the research phase was spent exploring binder chemistry. This section outlines the guiding philosophy behind the research; the people, contracts and hypotheses employed in the work; and the eventual evolution of the binder specification.

4.3.1 Guiding Philosophy

As noted in the Blue Book and reiterated in the Brown Book, there were five guiding principles or objectives related to the SHRP Asphalt Research Program and four of them were directly related to asphalt binder. They were as follows:

1. Identify and describe asphalt properties with a specific interest in the chemical and physical properties of asphalt cements and their interrelationships. The goal would be to correlate the chemical and physical characteristics of binders.
2. Develop improved testing and measuring systems for asphalt binders.
3. Establish the association between asphalt binder and pavement performance.
4. Develop an asphalt binder model that reflects the complex molecular structure of asphalt cement.

These guiding principles were used throughout the conduct of the research as benchmarks by the coordination contractor and the researchers to maintain focus. Furthermore, the guiding principles evolved into working hypotheses and models employed by the researchers, as seen in the following sections.

4.3.2 Hypotheses and Models Employed in the Binder Research

A thorough treatment of the hypotheses and models employed in the binder research is found elsewhere (*5*). The discussion in the following sections is intended to provide a brief overview.

4.3.2.1 Contract A-002A Binder Characterization and Evaluation (*5-9*)

Contract A-002A was led by Claine Peterson and Ray Robertson of Western Research Institute and Dave Anderson of Pennsylvania State University. It was the basis for the conceptualization and development of the asphalt binder performance-based specification. Also, this contract was the primary source of data used to generate the binder specification. The work was divided into three major tasks with the following objectives:

1. Identify and quantify the chemical, compositional factors in asphalt that significantly influence physical properties and the performance of asphalt-aggregate systems.
2. Develop new and improved techniques for measuring the physical properties of asphalt.
3. Develop standardized test methods for asphalt or modified asphalt which satisfy requirements of AASHTO and ASTM and which could be employed to specify and accept binders for use with performance-based specifications.

Chemical Composition and Performance of Asphalts

Hypothesizing that the chemical composition determined its physical (rheological) properties, the focus of the research was on the separation of asphalt into chemically distinct fractions. The asphalts were separated into five chemically distinct factors – neutral, weak acid, strong acid, weak base and strong base – by ion exchange chromatography (IEC). The results demonstrated that the strong acid fraction was the viscosity-building component in the asphalt and controlled its temperature susceptibility. Also, the data suggested that the strong acid fraction governs adhesion and water sensitivity through the interaction of polar functional groups and aromatic ring structures with aggregate surfaces. Finally, the data suggested that specific molecular entities in the strong acid fraction linked together into an elastic network, the structure of which affected the load and thermally-induced stresses that caused fatigue and low-temperature cracking, respectively.

Physical Properties and Performance of Asphalts

The selection of the most appropriate physical properties that merit characterization was driven by the distress modes (permanent deformation, fatigue cracking, thermal cracking, aging, moisture sensitivity and adhesion) encountered during the service life of the pavement. The behavioral modes that relate to the distress factors were rheology (stiffness), fracture, stress-strain characterization, tensile strength, asphalt-aggregate adhesion (debonding) and oxidative hardening. The physical property data should be developed from correlation with chemical, compositional properties since asphalt chemical structures varied with temperature and applied stress, and therefore so did their apparent molecular weights. Consequently, the general approach was to employ the concepts of physical chemistry, tempered with engineering judgment, by considering the physical (rheological) properties of asphalts as being directly related to their chemical properties. This approach is shown schematically in Figure 14.

Noting that asphalt is a viscoelastic material, the rheological behavior would depend on the loading time of the external force. Accordingly, shear susceptibility (complex flow) and temperature susceptibility (stiffness properties) were hypothesized as being reflective of component interactions of asphalts.

Finally, the researchers hypothesized that in the case of sophisticated chemical tests, surrogate physical tests would be developed to mimic the physicochemical parameters being evaluated. These physical tests would yield results in fundamental engineering units (stress and strain) to provide a sound link between standardized tests and field performance.

4.3.2.2 Contract A-004 Asphalt Modification (*5, 9*)

Since asphalt cements with optimum properties could not be obtained from all crude oils by conventional refining processes or blending practices, Contract A-004, led by David Rowlett of Southwestern Laboratories, focused on asphalt modification.

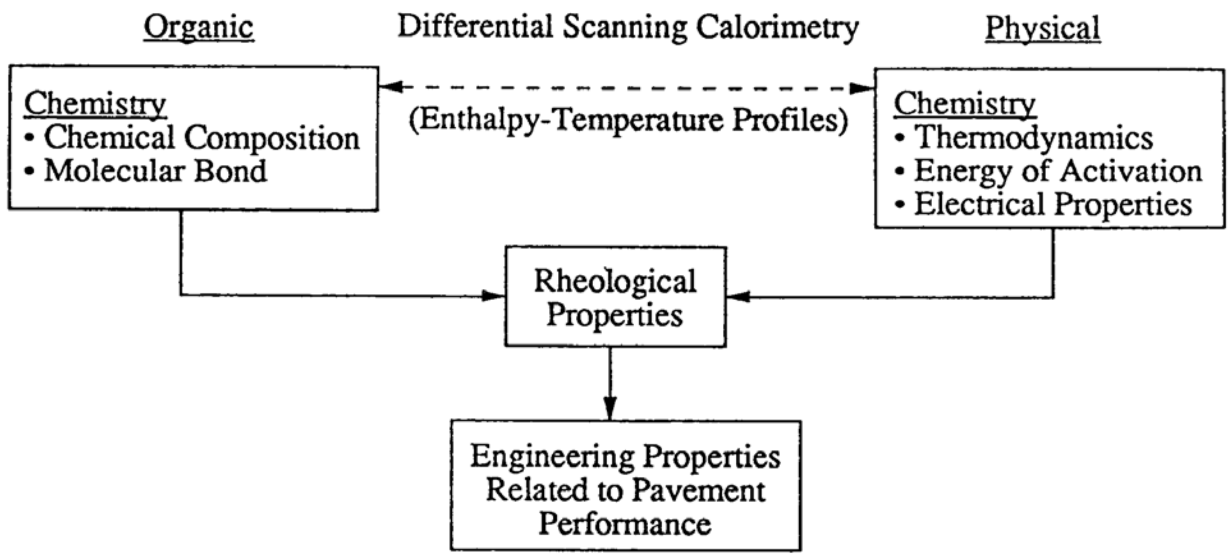


Figure 14 Relationship of asphalt organic and physical chemistry to asphalt physical properties (*5*)

Chemical Composition and Performance of Modified Asphalts

Logically, the working hypotheses employed in the area of modified binders were similar conceptually to those discussed for unmodified asphalts. Additionally, a working concept was advanced to investigate the molecular forces which produce an elastic network (entanglement) within modified asphalts. Theoretically, extensive branching of the asphalt molecules would decrease viscosity at low temperatures due to molecular motion of the functional end groups which are active at low temperatures. Similarly, extensive branching would increase viscosity at high temperatures and would introduce significant entanglement.

Performance-Related Physical Properties of Modified Asphalts

Close interaction and cooperation were required between the A-002A and A-004 contractors. The tests identified for unmodified asphalts would be employed with modified asphalts, if feasible. The objective, however, was to distinguish between those tests which simply characterized the presence of modifiers in asphalt from those which provided results that reflect the influence of the modifiers on the pavement performance factors.

4.3.2.3 Contract A-003B Fundamental Properties of Asphalt-Aggregate Interaction (*5, 9, 10*)

Led by Christine Curtis at Auburn University, Contract A-003B was tasked with providing fundamental information on the following:

- chemical nature of the asphalt-aggregate bond;
- chemistry and morphology of the aggregate;
- aggregate-induced asphalt chemistry; and
- changes in asphalt chemistry due to selective absorption and adsorption.

It was envisioned that these fundamental results would provide a direct link between the asphalt-aggregate chemistry and the pavement performance properties in terms of fundamental engineering properties as measured by accelerated laboratory test procedures.

Chemical Composition and Model Conceptualization

The model investigated considered interactions between the asphalt and aggregate surfaces occurring in three zones or regions as shown in Figure 15. Molecules absorbed within the pores of the aggregate constitute the absorbed region. Those molecules attached directly to the aggregate surface are considered as the interface region. Molecules that are structured near the interface but not attached to the aggregate surface are considered as the interphase region. The bulk asphalt lies beyond the interphase region.

Molecular structuring, which is often induced by aggregate chemistry, occurs in the asphalt at the interface and in the interphase regions. The researchers hypothesized that this structuring had a definite effect on the chemistry of the asphalt-aggregate mix and subsequently on the pavement performance characteristics. Furthermore, it was hypothesized that the asphalt absorbed within the pore space of the aggregate had different chemical and physical properties than the bulk asphalt such that selective absorption would occur; i.e., selective absorption of the highly polar molecules led to a situation in which the absorbed asphalt had a substantially different composition than the asphalt film. The net result was that the actual effective asphalt film coating the aggregate had a composition, and properties, which were different from the bulk asphalt.

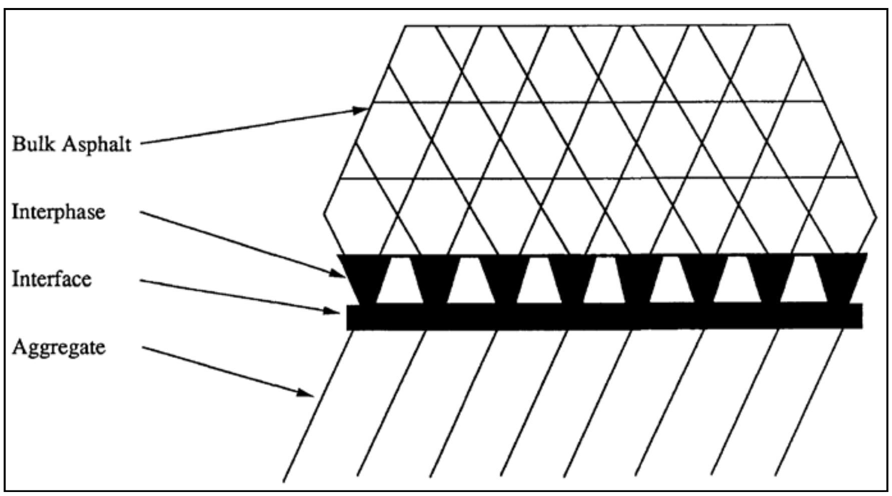


Figure 15 Asphalt-aggregate model illustrating interphase and interface regions (*5*)

Performance-Related Test Methods to Measure Asphalt-Aggregate Interactions

The approach pursued in contract A-003B was similar to those of A-002A and A-004 in that the rheological properties (viscoelastic, complex behavior) were explained in chemical terms by molecular association. Similarly, mechanical deformation (e.g., shear flow) was characterized as breaking or altering the intermolecular structure.

4.3.3 Evolution of Binder Specification

Had the SHRP Asphalt Program evolved as originally envisioned, the binder specifications would be based on the chemical composition of asphalt and common laboratory testing terminology would include IEC and FTIR instead of the now-familiar BBR, DSR and PAV.

The asphalt program began with an intensive laboratory investigation to relate the chemical and physical properties of asphalt to the behavior of asphalt mixes and pavement performance. The interest in a chemically based binder specification was still keen, as evidenced by statements made following the 1990 mid-course assessment (*3*):

> *"The emphasis in the asphalt research should continue to be on identification of the underlying chemical basis for permanent deformation, fatigue cracking, low-temperature cracking, moisture sensitivity, and aging. Tests of physical properties referenced in the binder specification should have a sound correlation with the underlying chemical properties of the asphalt. There should be a balance between chemical and physical tests."*

As the A-002A binder studies progressed, the researchers concluded that because each crude source contained unique and complex chemistry, measuring physical properties (fundamental engineering properties) was a much more effective and practical approach to predict performance. Quite simply, connecting chemical properties to pavement performance was "a bridge too far."

4.3.3.1 "Strawman," Supporting Tests and Criteria

As noted previously, the ultimate responsibility for developing a performance-based asphalt binder specification was that of the A-001 contractor. Integrating the work done by the A-002A and A-002B contractors, this activity was led by Tom Kennedy of the University of Texas at Austin. Essentially the specification required the selection of the grade to be based on the temperature regimen to which the pavement will be exposed (both high and low temperatures).

A decision was made to provide a "strawman" specification to public and private stakeholders interested in asphalt binder to inform them of the thinking of the research team and to obtain their feedback early in the development process. In all, approximately fifteen versions of the specification were developed and modified during the process as new information became available from both researchers and stakeholders. Examples of early editions of the strawman specifications are shown in Figures 16 and 17. Some have described the use of the strawman specification as a stroke of genius. Industry's initial response was somewhat less complimentary. Some in industry were skeptical. Others were downright incensed. In fact, one notably vocal individual is reported to have said it was "positively ridiculous" to proffer a specification when the research had not been completed.

“Strawman” Specification for Asphalt Binders
Graded at 0°C (32 F°) and 80°C (176°F) for aged binders

Property												
Rheology Index*. 0°C (32°F)	AB 21-20	AB 30-20	AB 40-20	AB 11-10	AB 15-10	AB 20-10	AB 6-5	AB 7.5-5	AB 10-5	AB 3-2.5	AB 4-2.5	AB 5-2.5
	2100±210	3000±300	4000±400	1100±110	1500±150	2000±200	600±60	750±75	1000±100	300±30	400±40	500±50
Rheology Index*, 80°C (176°F)	2000±200			1000±100			500±50			250±25		
Nitrogen Factor**	a ± for all grades											
Acid Factor**, max	b ± for all grades											
Healing Factor***, min	c ± for all grades											
Viscosity, 135°C (275°F), Ca, max	600 ± for all grades											
Flash Index. °C (F) min	d (d’)			e (e’)			f (f’)			g (g’)		

* Related to low-temperature cracking and permanent deformation. Test is conducted on aged binders. Binders are aged using low-temperature, high oxygen pressure test simulating 5 years of service life.

** Nitrogen factor and acid factor are related to moisture damage and are optional for regions without moisture damage problems or if the asphalt is modified. A surrogate test on the asphalt mixture can be substituted.

*** Related to fatigue cracking.

Figure 16 Example of Early “Strawman” Binder Specification

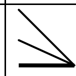
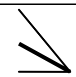
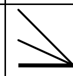
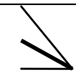
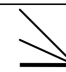
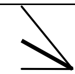
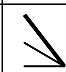
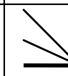
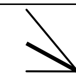
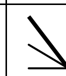
	Aged Asphalt Binder Grades											
		AB 1-			AB 2-			AB 3-			AB 4-	
	1	2	3	1	2	3	1	2	3	1	2	3
Highest mean monthly temperature °F		<80			80-90			90-100			>100	
Lowest anticipated temperature °F	<-20	-10 to -20	>-10	<-20	-10 to -20	>-10	<-20	-10 to -20	>-10	<-20	-10 to -20	>-10
Temperature dependency												
<u>Low-Temperature Cracking</u>												
Low-temperature stiffness at -10°F, psi (Bending Beam Test, SHRP B001)												
<u>Permanent Deformation</u> Dynamic stiffness at 140°F (Indentation Test, SHRP B002), psi												
<u>Fatigue Cracking</u> Cycles to failure at 77°F (Bending Beam Fatigue Test, SHRP B003), min												
Healing index at 77°F (Microcrack Healing Test, SHRP B004), min												
<u>Aging</u> Mass change (TFOT or RTFOT, AASHTO Test,), max., %												
Low-temperature stiffness SHRP B001 at -10°F max, psi												
After POV aging (POV Aging Test, SHRP B005) at temperature of, °F	120	120	120	140	140	140	160	160	160	180	180	180
<u>Water Sensitivity</u> Bond strength at 90°F (Blister Test, SHRP B006), min, psi												
<u>Adhesion</u> Bond strength at 32°F (Modified Blister Test, SHRP B006M), min, psi												
<u>Constructability</u> Kinematic viscosity at 275°F test (ASTM D2170), max cSt		1500			1500			1500			1500	
<u>Safety</u> Flash point (COC Flash Point, ASTM D92), max, °F		450			450			450			450	

Figure 17 Example of Early Strawman Binder Specification

4.4 ASPHALT-AGGREGATE MIX RELATED RESEARCH

At the onset of SHRP, specifications assured only that the asphalt binder would respond in a predictable, consistent manner during plant production and placement. There was, however, no minimum level of pavement performance warranted, or even intended, in any but a peripheral sense. Similarly, there were no mix specifications directly linked to pavement performance. Thus, a second major objective of the asphalt program was to develop a performance-based mix specification and supporting test protocols. This would also provide a means to verify the asphalt binder specifications being developed. In addition to the results produced though the SHRP contracts, the researchers were to consider the findings from related NCHRP projects 09-6(1), *Asphalt-Aggregate Mixture Analysis System (AAMAS)*, and 10-26A, *Performance-Related Specifications for Hot-Mix Asphalt*.

4.4.1 Guiding Philosophy

As with the binder specification, the mix specification was to accommodate both unmodified and modified binders and consider the six performance factors of low-temperature and fatigue cracking, permanent deformation, moisture sensitivity, aging and adhesion in conjunction with the effects of environmental conditions and traffic. Also, like the binder specification, a "strawman," Figure 18, was developed to focus the research, generate input from users and producers, and "to bring a sense of reality" to the end-products. As shown in Figure 19, the four environmental regimes defined by LTPP were included initially with the understanding that the regions might be further subdivided as the specification evolved and was adopted by the states. It is instructive to note the features of this initial asphalt-aggregate mix specification as it allows a comparison to what emerged upon the conclusion of the research. The specification addressed the following:

- A minimum number of traffic levels in terms of 18 kip ESALs were included in the initial specification with the ultimate goal of considering the possible interaction between traffic and environment.
- Conditioning procedures to address mix aging and moisture sensitivity were also envisioned. For aging of the loose mix, a modification of the rolling thin film oven test, forced draft oven, and high pressure aging vessel were suggested. For moisture sensitivity a triaxial compression type cell for measuring stiffness was proposed. Measuring permeability was also a possibility.
- To assess rutting potential, cylindrical specimens would be subjected to a vertical axial stress and to a repeated shear stress.
- For the two forms of low-temperature cracking (single drop in temperature and thermal fatigue), a thermal stress-restrained beam specimen test was envisioned.
- To capture the fatigue behavior of both thick and thin pavement layers, several tests were proposed: flexural beam, an axial push-pull, or some combination of tests which might serve as a surrogate.

- Although there was significant money and effort devoted to fundamental research on aggregate properties that affect adhesion and absorption, there were no provisions to address the more routine but critical factors which affect hot-mix asphalt performance; e.g., physical/mechanical properties of aggregate and aggregate gradation. Accordingly, the narrative in 4.5.6, *The Delphi Story*, is presented to describe how these critical but heretofore neglected elements of aggregate properties were addressed in the asphalt program. The importance of gradation was also recognized as evidenced by the initial requirements for VMA (voids in the mineral aggregate) and avoidance of the "restricted zone," shown in Figure 20.

Climatic Zone	Wet-No Freeze				Dry-No Freeze				Wet-Freeze				Dry-Freeze			
Highest mean monthly temperature, °F	90-100		>100		90-100		>100		90-100		>100		90-100		>100	
Lowest anticipated temperature, °F	-10 to -20	>-10	-10 to -20	>-10	-10 to -20	>-10	-10 to -20	>-10	-10 to -20	>-10	-10 to -20	>-10	-10 to -20	>-10	-10 to -20	>-10
Traffic Level[1]	L M H	L M H	L M H	L M H	L M H	L M H	L M H	L M H	L M H	L M H	L M H	L M H	L M H	L M H	L M H	L M H
Low-Temperature Cracking Stress at cracking, psi Temperature at Cracking, °F (Thermal Stress-Restrained Tensile Test, SHRP M001)																
Thermally-Induced Fatigue Cracking Cycles to Failure, N_f (Thermal Stress-Restrained Tensile Test, SHRP M001)																
Permanent Deformation Strain/cycle at 104 °F (Triaxial Compression-Repeated Shear Stress Test, SHRP M002)																
Fatigue Cracking Cycles to failure at 68°F, Nf (Beam Fatigue Test, SHRP M003)																
Short-Term Aging Stiffness aging index (Mixture Rolling Thin Film Oven Test, SHRP M004)																
Long-Term Aging Stiffness aging index (POV Aging Test, SHRP M005)																
Water Sensitivity Minimum retained stiffness, psi (Repeated Load-Triaxial Water Conditioning Test, SHRP M006)																

Figure 18 Strawman Specification for Asphalt-Aggregate Mixes

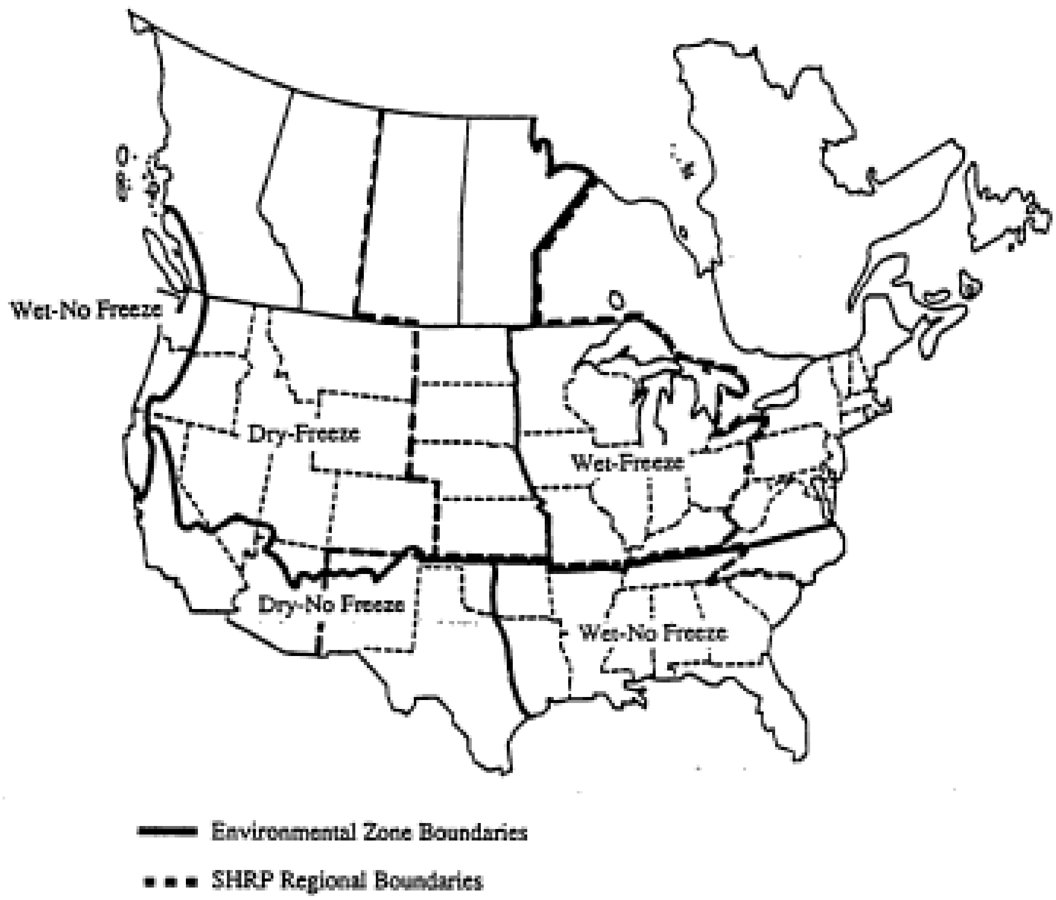


Figure 19 Environmental Regimes Defined by LTPP

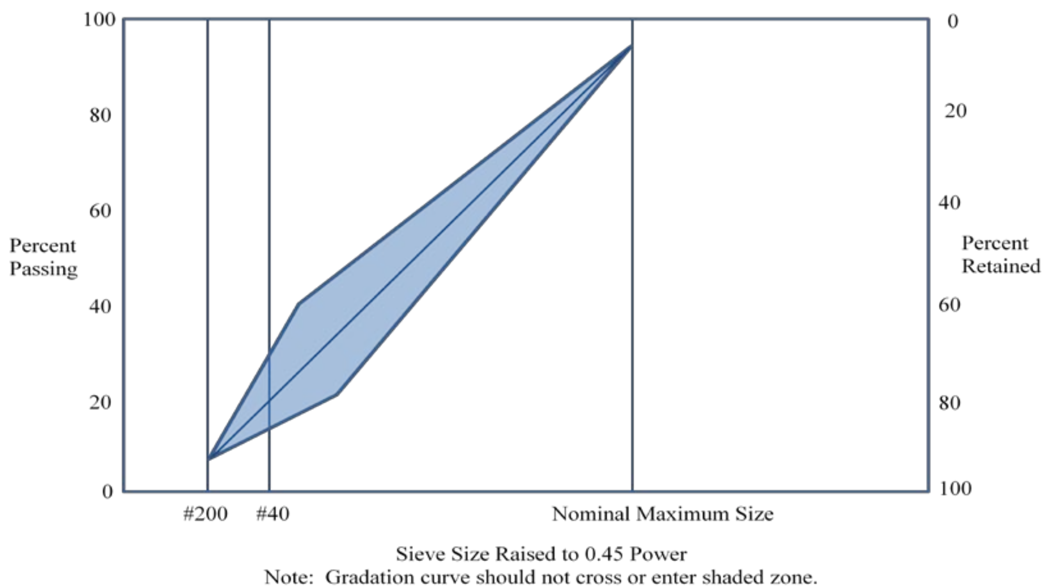


Figure 20 Restricted Zone for Aggregate Gradation

4.4.2 Hypotheses and Models Employed in the Mix Research

A thorough treatment of the hypotheses and models employed in the asphalt mix research is found elsewhere (*5*). The discussion in the following sections is intended to provide a brief overview.

4.4.2.1 Contract A-003A Performance-Related Testing and Measuring of Asphalt-Aggregate Interactions and Mixtures

This contract was considered a cornerstone of the asphalt program as it was to provide the foundation upon which accelerated performance-related tests would be developed for asphalt-aggregate systems. The fundamental knowledge of mix performance and material component interaction obtained in this research was critical to the development of the performance prediction models and the validation effort. Furthermore, this contract would provide the majority of the research data needed to conceptualize and develop the performance-based specification for asphalt-aggregate mixes. The principal investigator was Carl Monismith of the University of California-Berkeley. Co-principal investigators were Gary Hicks of Oregon State University and Fred Finn of Austin Research Engineers.

Given the shortcomings of the empirically-based Marshall and Hveem test methods, the goal was to develop theoretically sound, reliable and reproducible test methods that could be used to characterize asphalt mixes in terms of fundamental engineering properties. These properties would then be used to predict performance under a wide range of in-service conditions. Other factors that were to be considered in the development of these tests were practicality, efficiency and cost.

4.4.2.2 Contract A-005 Performance Models and Validation of Test Results

Bob Lytton of Texas A&M University and Rey Roque of Pennsylvania State University led this effort. Ideally, the second-stage validation of important relationships between asphalt properties and field performance could be accomplished through a long-term study of controlled field experiments. This approach, however, would require an estimated twenty or more years and was not compatible with SHRP's objective of rapid development of performance-based asphalt specifications. Therefore, this contract was structured to accelerate the validation process through a correlation of the relationships between asphalt properties and field performance, and the predictive performance models expressing these relationships. It was envisioned that statistical treatment of in-place field performance data coupled with sound judgment could be used in place of a long-term experiment.

A second and equally important goal was to develop performance prediction models using data from SHRP’s Long-Term Pavement Performance (LTPP) General Pavement Studies (GPS), state highway agencies, FHWA, and accelerated field tests such as the Pennsylvania State University test track and/or the FHWA's Accelerated Loading Facility (ALF).

It was essential to the success of the research to formulate relationships between asphalt binder, mix properties and field performance in a manner that realistically accounted for the effects of traffic, the environment, pavement layer geometry and construction.

4.4.2.3 Contract A-006 Performance-Based Specifications for Asphalt-Aggregate Mixtures

After the mid-course assessment this research, led by principal investigator Chuck Hughes, was folded into contract A-001. While the research conducted on the mix specification did not lend itself to the development of working hypotheses to guide the work, the starting points were conceptual frameworks generated by SHRP contract A-003A and NCHRP Project 10-26(A).

Conceptually, the performance-based specification would incorporate a mix analysis system; performance-related test methods; a modifier evaluation protocol; and specification tolerances for the various performance factors. It was envisioned that the performance-based specification would allow selection of an optimal job mix formula that would provide for satisfactory pavement performance over the wide range of environment, traffic loadings and construction conditions encountered in the United States and Canada. In addition, it would provide a structured method for estimating the probable effects of off-specification paving mixes on short- and long-term pavement performance.

4.5 PRODUCTS

Superpave (*Su*perior *Per*forming Asphalt *Pave*ments) was the final product of the SHRP Asphalt Program. It was envisioned to be a comprehensive system for the design and analysis of paving mixes to accommodate project-specific performance requirements. Encompassing new material specifications, test methods and equipment, and software, it was developed to address permanent deformation, fatigue cracking, and low-temperature cracking as tempered by aging and moisture sensitivity, and was conceived to be applicable to virgin and recycled, dense-graded hot-mix asphalt, with or without modification. Lastly, it was hoped that it would replace the diverse and numerous material specifications and mix design methods then used by the fifty states with a single system that could provide results tailored to the distinct environmental and traffic conditions found anywhere in the United States and Canada. Specifically, the major products included the following:

1) a performance-based specification for asphalt binders with supporting test methods and equipment;
2) a performance-based mix design system with supporting test methods and equipment;
3) a modifier evaluation protocol; and
4) the Superpave specification, design, and support software.

The evolution of the Superpave products was fraught with challenge and debate. The evolution of the name was no less contentious. “What’s in a name?” you ask. Read on for a behind-the-scenes tale of how “Superpave” came to be.

What's In a Name?

The NCHRP 9-6 research project developed recommendations for a mix design system called the Asphalt-Aggregate Mixture Analysis System (AAMAS).

During the early days of SHRP before plans were made for a mix design system, there was often reference to AAMAS. But then there was confusion, "Are you talking about NCHRP AAMAS or SHRP AAMAS?"

And so in Denver one night after frustration at the confusion, a new term was coined, Mix Design and Analysis System, MiDAS. This not only differentiated SHRP from NCHRP; it had a marketable ring.

But, within a short time, SHRP staff in Washington decided that the system should not be called MiDAS. Reasons given were that Midas was the name of a common muffler shop which would not be a flattering comparison. Of course there was also the fable about King Midas, which was considered to be a sad story. After all, King Midas died of starvation because everything he touched turned to gold. It would not be good to have such a negative image as part of the SHRP Program. There also seemed to be some pride of authorship issues. SHRP staff were in charge of the program, and they would retain naming rights.

So a new name was coined, SUperior PERforming AsPHALT, or SuperPhalt. So, during the summer of 1991, the system was officially known as SuperPhalt. The retort became, "What is that? A rough concrete pavement with extreme faulting?"

Then, in October 1991, at the AASHTO trade fair in Milwaukee where the SuperPhalt system was on display, the message about the name was communicated to SHRP leadership. The response? Well, no we can't use MiDAS because of the negative image associated with that.

And so, a new name was coined, Superpave, short for SUperior PERforming asphalt PAVEments. And, so it is today.

4.5.1 Binder Specification and Supporting Tests

The binder specification (AASHTO MP 1), as originally configured at the end of SHRP, is shown in Table 5. The grading system, designated "PG" for performance grade is intended to capture the binder's contribution to pavement performance as measured by permanent deformation, fatigue cracking, and low-temperature cracking. The specification also contains requirements for safety and constructability. The properties at three temperatures to which the pavement will be exposed – high, intermediate, and low – define the binder grade. The properties include the following:

- $G^*/\sin\delta$ measured with the dynamic shear rheometer (DSR) on the unaged binder and residue from the rolling thin film oven (RTFO) test;
- $G^*\sin\delta$ on the pressure aging vessel (PAV) residue along with stiffness and m-value from the bending beam rheometer (BBR).

The objective of the SHRP Asphalt Research team was to provide, in general, tests that captured fundamental properties yet were reliable, simple, and affordable. Where possible, the team was encouraged to use existing test equipment and protocols. That said, the researchers used several approaches to measure fundamental properties or to "condition" the binder. They developed completely new test devices such as the bending beam rheometer (BBR) and pressure aging vessel (PAV). They built upon existing empirical measurements such as ductility to capture failure properties through the direct tension tester (DTT). Borrowing concepts from the chemical industry, the researchers reconfigured rheometers to capture binder properties over a range of temperatures and frequencies. The equipment and test protocols initially developed to support the binder specification included the following:

- Bending Beam Rheometer (AASHTO TP 1) for low-temperature stiffness;
- Dynamic Shear Rheometer (AASHTO TP 5) for intermediate and high temperature stiffness and phase angle;
- Direct Tension Test (AASHTO TP 3) for low-temperature fracture properties; and
- Pressure Aging Vessel (PAV) (AASHTO PP 1) to simulate long-term aging.

Additional existing binder tests supporting the specification included the following:

- Rolling Thin Film Oven Test (RTFOT, AASHTO T 240, and ASTM D2872) to simulate short-term aging;
- Rotational Viscometer (ASTM D4402) for high temperature viscosity and constructability;
- Flash Point (Cleveland Open Cup, ASTM D92) for safety;
- Mass Loss (AASHTO T 240) for volatile loss, and
- Solubility (AASHTO T 44) to assure homogeneity (or to assure no contaminants).

Performance Grade	PG 46-			PG 52-							PG 58-					PG 64-					
	34	40	46	10	16	22	28	34	40	46	16	22	28	34	40	10	16	22	28	34	40
Average 7-day Maximum Pavement Design Temp, °C	<46			<52							<58					<64					
Minimum Pavement Design Temperature, °C	>-34	>-40	>-46	>-10	>-16	>-22	>-28	>-34	>-40	>-46	>-16	>-22	>-28	>-34	>-40	>-10	>-16	>-22	>-28	>-34	>-40
Original Binder																					
Flash Point Temp, T48, Min °C	230																				
Viscosity, ASTM D4402, Max, 3 Pa·s, Test Temp, °C	135																				
Dynamic Shear, TP 5, G*/sin δ, Min, 1.00 kPa, Test Temp @ 10 rad/s. °C	46			52							58					64					
Rolling Thin Film Oven (T240)																					
Mass Loss, Max, percent	1.00																				
Dynamic Shear, TP 5, G*/sin δ, Min, 2.20 kPa, Test Temp @ 10 rad/s. °C	46			52							58					64					
Pressure Aging Vessel Residue (PP1)																					
PAV Aging Temperature, °C	90			90							100					100					
Dynamic Shear, TP 5, G*sin δ, Max, 5000 kPa, Test Temp @ 10 rad/s. °C	10	7	4	25	22	19	16	13	10	7	25	22	19	16	13	31	28	25	22	19	16
Physical Hardening	Report																				
Creep Stiffness, TP1 S, maximum, 300.0 MPa, m-value, Minimum, 0.300 Test temp @ 60 s, °C	-24	-30	-36	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30
Direct Tension, TP3 Failure Strain, Min, 1.0% Test temp @ 1.0 mm/min, °C	-24	-30	-36	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30

Table 5 Performance Graded Asphalt Binder specification (AASHTO MP 1)

PERFORMANCE GRADE	PG 64-						PG 76-					PG 82-				
	10	16	22	28	34	40	10	16	22	28	34	10	16	22	28	34
Average 7-day Maximum Pavement Design Temp, °C	<70						<76					<82				
Minimum Pavement Design Temperature, °C	>-10	>-16	>-22	>-28	>-34	>-40	>-10	>-16	>-22	>-28	>-34	>-10	>-16	>-22	>-28	>-34
ORIGINAL BINDER																
Flash Point Temp, T48, Min °C	230															
Viscosity, ASTM D4402, Max, 3 Pa·s, Test Temp, °C	135															
Dynamic Shear, TP 5, G*/sin δ, Min, 1.00 kPa, Test Temp @ 10 rad/s. °C	70						76					82				
ROLLING THIN FILM OVEN (T240)																
Mass Loss, Max, percent	1.00															
Dynamic Shear, TP 5, G*/sin δ, Min, 2.20 kPa, Test Temp @ 10 rad/s. °C	70						76					82				
PRESSURE AGING VESSEL RESIDUE (PP1)																
PAV Aging Temperature, °C	100 (110)						100 (110)					100 (110)				
Dynamic Shear, TP 5, G*sin δ, Max, 5000 kPa, Test Temp @ 10 rad/s. °C	34	31	28	25	22	19	37	34	31	28	25	40	37	34	31	28
Physical Hardening	Report															
Creep Stiffness, TP1 S, maximum, 300.0 MPa, m-value, Minimum, 0.300 Test temp @ 60 s, °C	0	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	0	-6	-12	-18	-24
Direct Tension, TP3 Failure Strain, Min, 1.0% Test temp @ 1.0 mm/min, °C	0	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	0	-6	-12	-18	-24

Table 5 Performance-Graded Asphalt Binder Specification (AASHTO MP 1) Continued

4.5.2 Other Binder-Related Products

The A-003B team, studying asphalt-aggregate interactions, produced two major products from their work: models for adhesion and stripping, and the net adsorption test. The net adsorption test provided a method for determining the affinity of an asphalt-aggregate pair and its sensitivity to water. Other products included a limestone reactivity test and a test to determine the reactivity of different asphalt-aggregate systems when anti-stripping agents are used. The team concluded that aggregate properties are more influential in adsorption and stripping potential as compared to asphalt properties.

Neither the net adsorption test nor the limestone reactivity test, though effective screening tools, is used routinely today.

Probably the most significant product from the A-IIR studies was the pavement core tomography work conducted at the University of Southern California under the guidance of Professor Costas Synolakis. This technology has evolved and is being used today in practice. Other significant efforts from the A-IIR contracts assisted the A-002A contractor in understanding specific chemical and physical characteristics that relate to performance.

4.5.3 Mix Design System and Software

The Superpave mix design and analysis system, hierarchical in nature and vertically integrated, is illustrated conceptually in Figures 21 and 22. Three levels of design were defined based on traffic with suggested boundary values at 1 million and 10 million ESALs. As shown, all three design levels included a volumetric mix design phase. In levels 2 and 3, accelerated performance-based tests were recommended to facilitate mix optimization for resistance to permanent deformation, fatigue cracking and low-temperature cracking.

For level 1, the laboratory mix design involved only volumetric design, which evaluates aggregates and asphalt binders to select a gradation and asphalt binder content to satisfy specified criteria for air voids, voids in mineral aggregate, and voids filled with asphalt. For levels 2 and 3, performance-based tests would be conducted and estimates of distress with time would be made. This would allow the mix design to be optimized with regard to one or more of three distresses; permanent deformation, low-temperature cracking, and fatigue cracking.

It was anticipated that the majority of the mix designs would use the level 1 and level 2 procedures, while level 3 would be used for pavements expected to carry very heavy traffic loads (more than 10^7 ESALs over the anticipated service life) or roadways of critical importance.

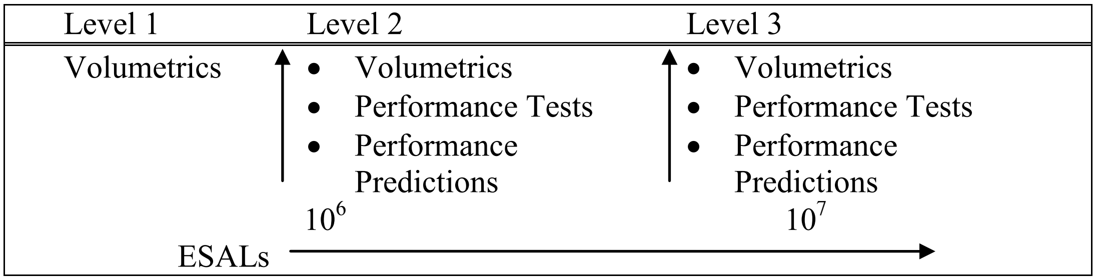


Figure 21 Hierarchical Organization of the Superpave Mix Design and Analysis

Level 3 also included an optional proof testing scheme that would allow the mix to be subjected to tests simulating the actual traffic and environmental conditions to confirm that the mix actually would perform at the desired level.

In level 2 mix design, fewer tests were to be performed at fewer temperatures than for level 3 mix design. Performance-based tests for permanent deformation were to be done at a single effective temperature for permanent deformation. Likewise, tests used to predict fatigue cracking were to be performed at a single effective temperature for fatigue cracking. Low-temperature tensile strength was measured at a single temperature in level 2 design.

Level 3 mix design simulated the entire year by breaking it into representative seasons. Performance-based tests for permanent deformation and fatigue cracking were performed over a range of temperatures. A larger slate of tests was proposed to more rigorously evaluate mix response across a greater range of stress. Permanent deformation and fatigue cracking were predicted using mix properties in each of the representative seasons. A summary comparison of level 2 and level 3 is shown in Table 6.

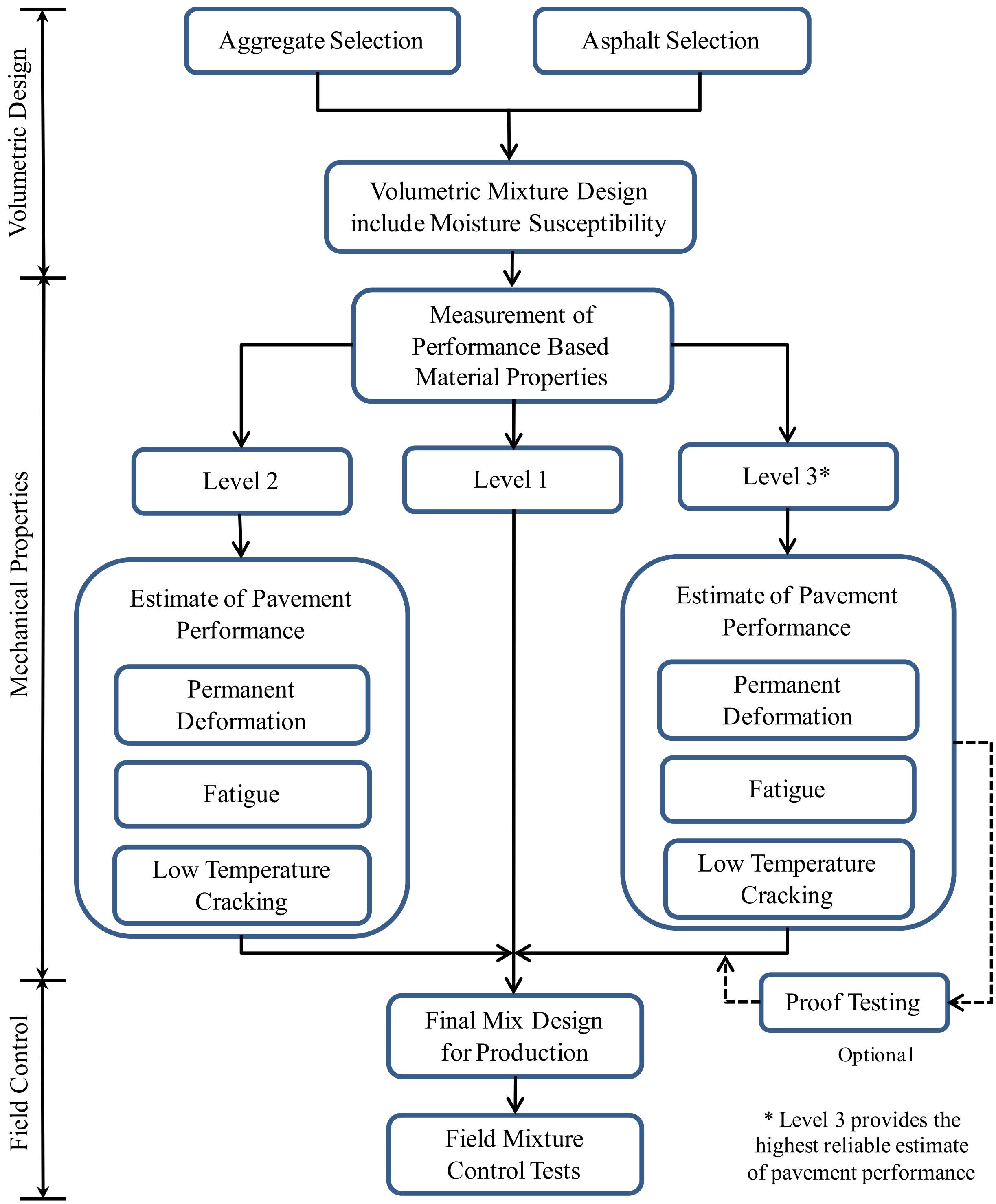


Figure 22 Flowchart for Superpave Mix Design and Analysis

Table 6 Comparison of Level 2 and Level 3 Mix Design Methods

	Permanent Deformation/ Fatigue Cracking	Low-Temperature Cracking
Test Types	Level 3 considers more states of stress and requires two additional test methods	No difference between level 2 and level 3
Test Temperatures	Level 3 considers range of temperatures from 4 to 40°C	Level 3 considers three temperatures
	Level 2 uses one effective temperature for fatigue cracking and one for permanent deformation	Level 2 considers tensile strength at one temperature only
Performance Prediction	Level 3 breaks the year into seasons	No difference between level 2 and level 3
	Level 2 considers the entire year as a single season	

As originally configured, equipment and test protocols supporting the Superpave mix design system included the following:

- Gyratory or Rolling Wheel Compaction.
- Short and Long-Term Aging (Forced Draft Oven).
- Simple Shear Test for permanent deformation and fatigue cracking.
- Indirect Tensile Creep and Strength for low-temperature cracking.
- AASHTO T 283 or Environmental Conditioning System for moisture sensitivity. An optional test, the net adsorption test, was available to screen for asphalt-aggregate compatibility.

The Superpave software was intended to integrate the specification, mix design and support routines into one program. It was designed to guide the mix design process from beginning to end and provide an orderly, self-contained means for the recording of all test data and analysis results, performance predictions, and other information required for a complete mix design at levels 1, 2 and 3.

4.5.4 Modifier Evaluation Protocol

The Superpave practice for modifier evaluation, as originally described in AASHTO Provisional Practice PP 5, provided a framework for identifying the need for a modifier and estimating its performance. Additionally, it facilitated a simple cost comparison of modified vs. unmodified mixes. Finally, it provided guidance on other aspects of modifiers such as purity, toxicity, storage stability and compatibility.

The standard was not widely used and was eventually dropped. Some features of PP 5 are incorporated in AASHTO R 15, Standard Practice for Asphalt Additives and Modifiers.

Research addressing modified binders was conducted under NCHRP 9-10, *Superpave Protocols for Modified Binders*, and other research.

4.5.5 The Gyratory Story

One of the most visible differences in the current Superpave method of mix design is the gyratory compactor. The story of its selection starts before the SHRP Program began.

In January 1987, NCHRP initiated a contract (NCHRP 9-6) called the Asphalt-Aggregate Mixture Analysis System. This work was intended to be a precursor to and in support of the SHRP Program. A major part of the research effort was to look at different methods of laboratory compaction and make a recommendation to be followed in SHRP. Methods investigated included (*11*):

- Marshall compaction (mechanical, static-base, flat face),
- Marshall compaction (mechanical, rotating base, slanted face),
- Marshall compaction (hand compaction),
- Kneading compactor,
- Vibratory hammer,
- Simulated rolling wheel (quarter circle),
- Vibrating, kneading compactor and
- Gyratory compactor (Texas 4-inch gyratory).

The key method of evaluating each type of compaction was to compare laboratory-compacted specimens to field-compacted specimens. The comparison was based on Marshall stability, resilient modulus, tensile strength and aggregate orientation.

One outcome of the NCHRP 9-6 research was the recommendation for gyratory compaction to be used as a part of the preliminary mix design method developed at the direction of the NCHRP project panel. This method became known as the Asphalt-Aggregate Mix Analysis System (AAMAS). In the final report, the Corps of Engineers gyratory test machine was specifically mentioned although a Texas gyratory had been used in the research (*11*).

The later part of this NCHRP study overlapped with the commencement of the SHRP research. So, one of the early questions for the A-006 contract to investigate was which gyratory compactor to specify.

4.5.5.1 History of Gyratory Compaction

Gyratory compaction can be traced back to the Texas Department of Highways in 1939. The Department began a study for the design and control of hot-mix asphalt. A key part of that work was the investigation of a laboratory compactor. Two criteria were used: first, the compactor should achieve the final density of the pavement after being subjected to traffic, and second, aggregate break down should approximate break down in the field (*12*). A total of nine potential compactors were tried including various types of shearing or kneading compactors, impact compaction, static compaction, vibratory compaction, pneumatic tire compaction, and miniature rolling wheel compaction. In the end a shearing compactor was selected. Phillippi, Raines and Love, all of the Texas Department of Highways, developed the manual compactor shown in Figures 23 and 24.

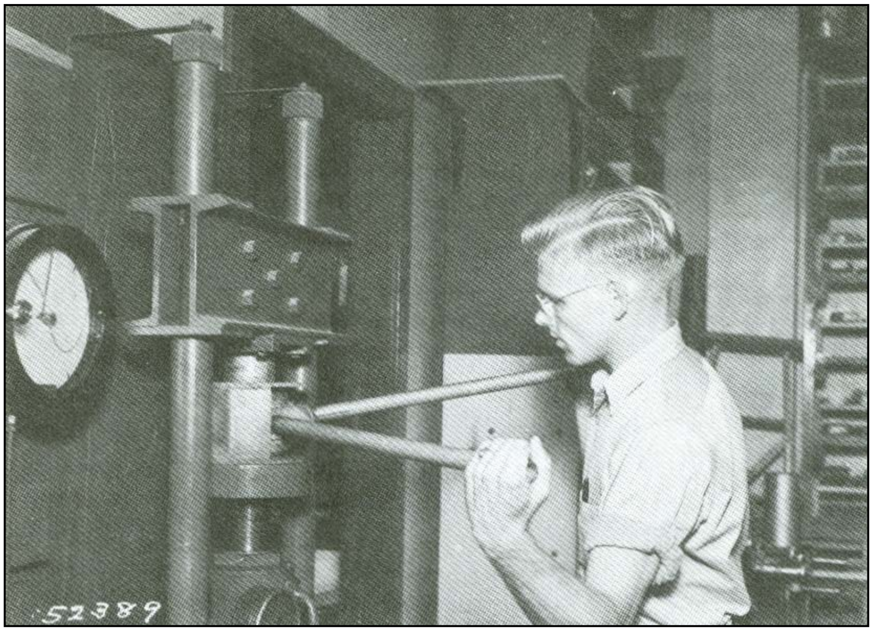


Figure 23 Compacting a Sample using a Manual Texas Gyratory Compactor (circa 1950)

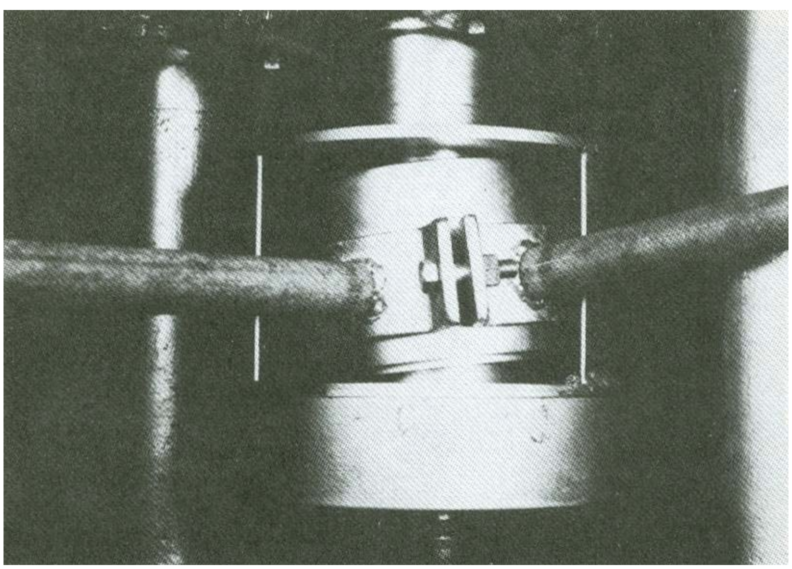


Figure 24 Close Up of Mold in Manual Texas Gyratory Compactor

The mold was a piece of pipe with an inside diameter of 4 inches and a wall thickness of ½ inch. It was placed between two horizontal plates with an opening ½ inch greater than the height of the mold. Handles were attached to supports clamped to the outside of the mold, and the mold was twisted so opposite corners of the mold contacted the top and the bottom plates. By chance, the angle happened to be approximately 5 degrees and 40 minutes.

In the early 1950s, the Texas Department of Highways developed a mechanized compactor that faithfully matched results obtained from the manual method. The compaction protocol consisted of groups of three gyrations applied at one gyration per second. At the beginning of each group, the vertical pressure was adjusted to 50 psi. Groups of gyrations continued until one pump of the hydraulic ram created a vertical pressure of 150 psi. If the pressure was less than 150 psi, then another set of gyrations was applied. This became the standard laboratory compaction method.

In the 1960s, a large-scale version was developed for base mixtures containing larger aggregate size. The compaction protocol was entirely different. The gyrations were applied continuously at a rate of 30 per minute instead of in groups of three. The angle was an even five degrees. Specimen height was monitored and the compaction was stopped when the specimen height changed less than a specified amount per gyration.

One other variation of the Texas 4-inch gyratory compactor was the Oklahoma gyratory compactor. Oklahoma decided to adopt gyratory compaction. They purchased compactors from the only commercial manufacturer. After a period of time, it was discovered that the angle was about one degree less than the Texas version. Rather than invalidate existing mix designs, the Oklahoma Department of Highways decided to keep the angle that had been used rather than adjust to match the Texas compactors.

In the late 1950s, John McRae of the U.S. Army Corps of Engineers started development of the Corps of Engineers gyratory test machine (GTM), shown in Figure 25. Intrigued by the principle of gyratory compaction, he developed a compactor that measured changes in mixture response during compaction. Unlike the Texas machine that used three points to hold the angle constant during compaction, the GTM used two points across the diameter of the specimen. The mold was free to rotate about the two points allowing the angle to float. McRae developed parameters to evaluate the mix based on the change of angle.

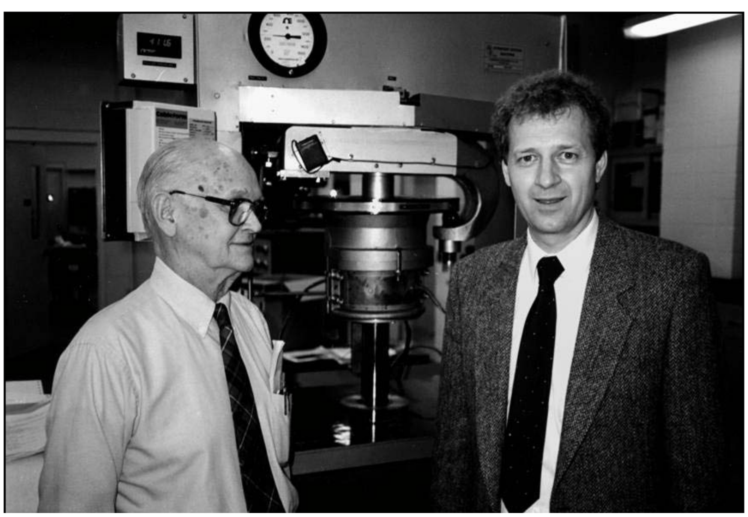


Figure 25 Inventor John McRae and Gerry Huber stand before a Corps of Engineers Gyratory Test Machine, circa 1990

In 1959 a delegation from France visited the United States and observed both the Texas gyratory compactor and the Corps of Engineers compactor. Curious about parameters of gyratory compaction, the Laboratoire Central des Ponts et Chausees (LCPC) undertook studies throughout the 1960s. LCPC was in the midst of developing a new method of mix design, and the gyratory compactor was incorporated as part of the new method.

The French gyratory compactor, shown in Figure 26, applied a constant angle of one degree. Francis Moutier of the LCPC performed studies on the compactor. By monitoring specimen height, density was tracked during compaction. The relationship of density to the log of the number of gyrations was found to be nearly linear.

In the fall of 1990, based on the NCHRP 9-6 findings that gyratory compaction most closely simulated field compaction, the discussion within the SHRP research team focused on which gyratory compactor should be used. This led to an investigation of the history of gyratory compaction.

Also in the fall of 1990, the Texas DOT arranged for loan of a 6-inch Texas gyratory to the Asphalt Institute for the research effort. Interestingly, the engineer who arranged for the loan made the assumption that the Texas protocol would be part of Superpave. Post-SHRP he expressed his disappointment that SHRP had not adopted the Texas method.

Figure 26 Francis Moutier with Second Generation LCPC Gyratory Compactor, circa 1998

4.5.5.2 Selection of SHRP Gyratory Compactor

In May 1991, Gerry Huber was part of a panel that travelled to France to review French highway technology. The LCPC laboratories in Nantes, where Francis Moutier was located, was one of the stops. Moutier provided French technical articles that discussed development of the French method of mix design, including developmental studies that had been done.

By the summer of 1991 a picture of the gyratory state of knowledge had been developed. It can be summarized as follows.

- For the Texas 4-inch compactor there was no information about selection of operating parameters. An AAPT paper in 1952 (*12*) documented the development of the mechanized compactor, but its development was based solely on matching density results obtained with the manual method.
- The Texas 6-inch compactor was interesting in that specimen height was monitored and the end point of compaction was based on a specified rate of change.
- The GTM was more of a testing machine than a compactor. In the summer of 1991, the vision of using mixture tests to predict performance still permeated the research vision. As a result, the various parameters that had been developed for the GTM were not interesting to the research effort because they were empirical.
- The LCPC gyratory had several interesting components. Work had been done on compaction vs. gyrations for a number of mixtures and had been related to aggregate properties as well as rutting performance in the field. Studies had been done on specimen size parameters and relation to maximum aggregate size. Also, studies had been done on the angle of gyration.

So, the technical direction was selected. SHRP would use the principles of the LCPC compactor, but needed to evaluate and make changes to the protocol.

4.5.5.3 Development of the Superpave Gyratory Compactor

Decisions on the operating parameters of the proposed compactor were set as follows:

- The one degree angle of LCPC was accepted;
- The vertical pressure of 600 kPa of LCPC was accepted, but
- The LCPC speed of gyration of 6 gyrations per minute was not accepted.

LCPC had addressed concern about specimen cooling during the 10 to 20 minute compaction time by installing an electrical heating system around the mold. The slow speed of gyration was based on a 1960s version of the compactor that included a load cell to measure the eccentric force. And, although the eccentric force was not part of the final protocol, the speed remained fixed at 6 gyrations per minute. For SHRP Tom Kennedy decided to investigate higher speeds of gyration.

The first step was to obtain a gyratory compactor that could be modified for performing experiments. A Texas 6-inch compactor was obtained on loan from the Texas Department of Transportation. As shown in Figures 27 through 29 it was modified as follows:

- To reduce the speed of rotation to 6 gyrations per minute, a frequency modulator was added to the power supply. The Texas standard was 30 gyrations per minute, while the LCPC compacted at 6 gyrations per minute.
- The vertical pressure was already adjustable, so it could be matched to LCPC.

- On this gyratory the angle was induced by a cam on a lever. A new cam was made to change the angle from 5 degrees to one degree.

Figure 27 Modified Texas Six-Inch Gyratory Compactor at the Asphalt Institute. Note pressure gauges at top of machine, spring 1991

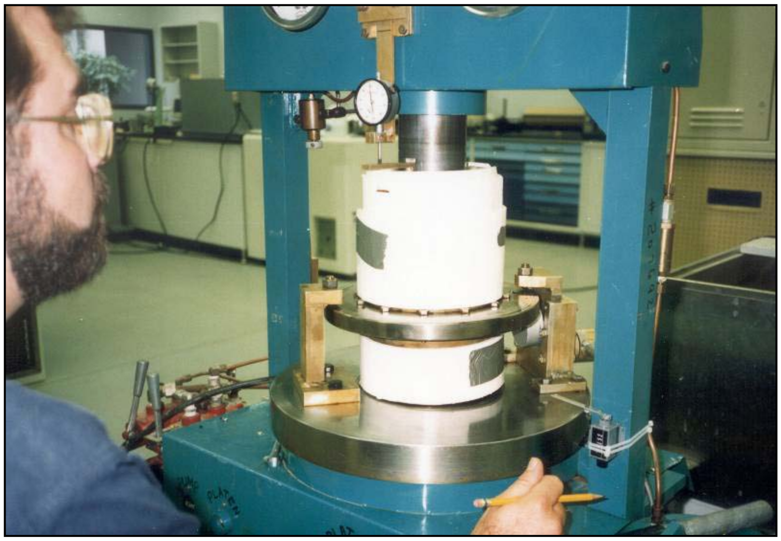


Figure 28 Turntable and mold. Molds had temporary insulation applied to the outside. Note dial gauge for measuring height of the ram inside the mold, spring 1991.

Figure 29 Angle is applied by rotating the handle and raising the side of the mold. Handle is removed before rotation (gyrations) start, spring 1991

Speeds greater than 30 gyrations per minute were not investigated because the maximum speed of the Texas gyratory was 30 gyrations per minute. Changing the mechanism of the Texas 6-inch gyratory to increase the speed was too difficult. Besides, the time savings obtained by increasing to 45 or 60 gyrations per minute were not as great as increasing the speed from 6 to 30. So the decision was made to use 30 gyrations per minute as the standard.

In July 1992 the Rainhart Company delivered the first prototype Superpave compactor, shown in Figure 30. It was available just in time for an open house in Tomah, Wisconsin, the first trial SPS-9 project to produce and place Superpave hot mix.

Figure 30 First Prototype Superpave Compactor. Machine designer, Ed Hamilton, on left. Company owner Larry Hart on right. Taken at Rainhart Company, Austin, Texas, July 1, 1992

The mix design for the project had been done on the modified Texas gyratory at the Asphalt Institute but the prototype was to be used for quality control in the FHWA field laboratory.

Immediately there were problems. The bearings were undersized for the loads being applied and failed rapidly (see Figure 31). Compliance of the compactor frame was also an issue. The frame visibly flexed during compaction.

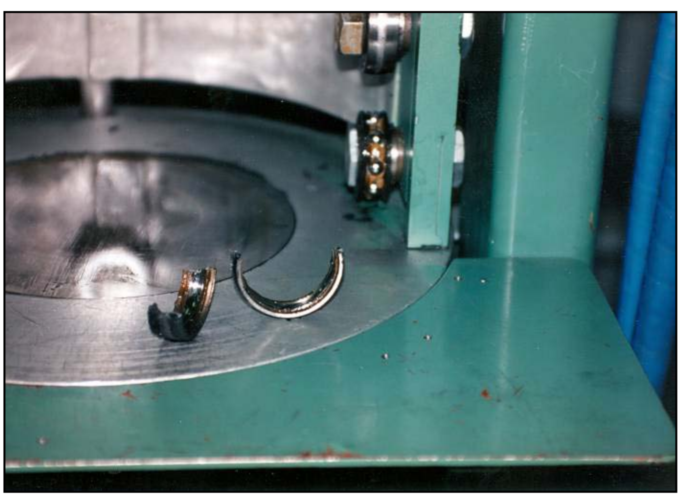


Figure 31 Bearing problems on first prototype Superpave gyratory compactor, Tomah, Wisconsin, July 8, 1992

The next field trial occurred three weeks later in Waukesha, Wisconsin, on I-43. Again, the mix designs were done at the Asphalt Institute on the modified Texas 6-inch gyratory. For quality control testing that modified Texas gyratory was hauled to Wisconsin in a rented box truck. Jack Weigel, Quality Control Manager of Payne and Dolan, graciously purchased a transformer so that the researchers could get the necessary 220 volt power in the lab trailer at the plant from the 440 volt generator system used to run the hot-mix plant.

The next trial field section was scheduled for September 24, 1992, on I-65 at West Lafayette, Indiana. The Rainhart prototype compactor had been redesigned, and it was being used for the design. A week before construction, it was discovered that the Rainhart and the modified Texas 6-inch compactors produced different mix designs.

An investigation was launched, and it was quickly discovered that the angle of gyration (externally measured) was different between the two machines. Studies were done and it was determined that the prototype compactor that was supposed to have an angle of 1 degree actually had an angle of 1.27°. In the end it was decided that the angle should be standardized at 1.25°. (See *So, How Did the Angle Change?*)

So, How Did the Angle Change?

It was based on a mistake.

In 1991 a Texas 6-inch gyratory compactor was modified to change the angle from five degrees to one degree in preparation for laboratory studies about gyratory compaction. The angle was applied with a cam, which raised the side of the mold when rotated. A new cam was made to reduce the lift, but the cam was incorrectly made.

In September 1992, the Texas modified-gyratory compactor was discovered to have an angle of 1.27°. Work on the design compaction levels had been done on this compactor, and the decision was made to complete the work with the angle as is.

The July 1993 Pacific Rim Conference in Seattle was selected for roll out of Superpave. On July 26th, at the conference, a meeting was held with the SHRP Asphalt Advisory Committee, SHRP executives, FHWA and the researchers to finalize the standard. (See Figure 32.) After review it was agreed that the larger angle should be used, but it was decided to use 1.25° as the angle, not 1.27°.

Figure 32 Figure 32 SHRP Asphalt Advisory Committee meeting, July 26, 1993. It was at this meeting that the final decision about the angle for the gyratory compactor was made. Back row L-R Gerry Huber (SHRP A-001 Contract), unidentified, unidentified, Tony Kriech (Asphalt Materials), unidentified, Haleem Tahir (Maryland Department of Transportation), Dale Decker (NAPA), and John d'Angelo (FHWA). Front row L-R Chuck Hughes (former Virginia Research Council), Damien Kulash (SHRP Manager), Gale Page (Florida Department of Transportation), Ed Harrigan (SHRP Asphalt Program Manager), Eric Harm (Illinois Department of Transportation) and Peter Bellin (SHRP loaned staff from Germany)

4.5.5.4 Density Gradient in Gyratory Specimens

The LCPC compactor could be used with 80, 120 and 160 mm diameter molds. LCPC had done some experiments looking at these three mold sizes using 10 mm maximum size and 20 mm maximum size mixtures. They found that the compaction characteristics remained the same as long as the ratio of diameter to maximum particle size remained above 6 (*13*).

The Texas compactor had a six inch mold, so the decision was made to do all SHRP testing with the six inch mold. When specifications were put together for the Superpave gyratory compactor, one concern of the industry was the amount of material that would be required to switch from 4-inch Marshall specimens to 6-inch Superpave specimens. As a result, the specifications were written to include a 100 mm diameter mold in addition to a 150 mm diameter mold. This was done without testing to confirm that the compaction characteristics reported by LCPC held true for North American mixtures. As an aside, the Colorado Department of Transportation is the only agency to adopt use of the 100 mm molds.

A second experiment was done to investigate density gradients in the compacted samples. LCPC had standardized a height to diameter ratio of approximately one. The final height of a 160 mm diameter specimen is targeted to be 150 mm. A zone of disturbance approximately equal to the radius of the mold was known to exist within the mold. The zone of disturbance is shown in Figure 33 for different height to diameter ratios.

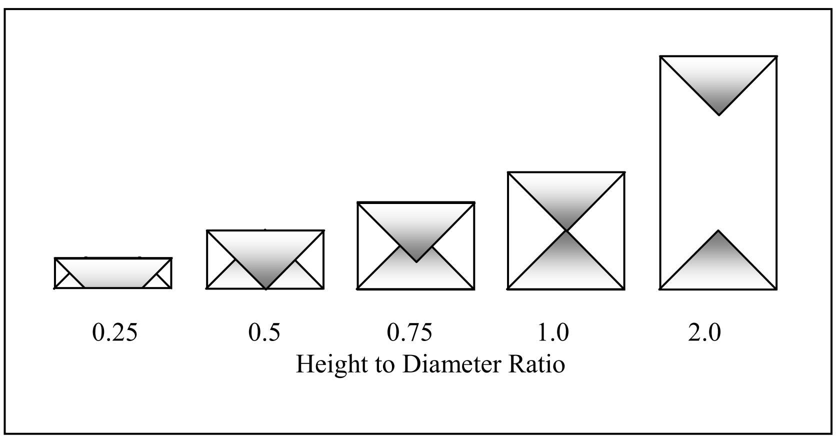


Figure 33 Effect of Height to Diameter Ratio on Compaction in Gyratory Compactor

It was known from the LCPC literature that density gradients exist in gyratory-compacted specimens. Tall specimens have a portion at the center that receives less shearing action and hence less compaction. If the specimen is significantly shorter than the diameter, then the compaction effect is reduced because the zone of disturbance cannot form properly. The compaction plate on the other side of the mold interferes with it.

Therefore, a decision was made to investigate density gradients in gyratory-compacted specimens in order to select a height to diameter ratio that produced density gradients similar to the density gradient of field-compacted mix.

The NCHRP 9-6(1) AAMAS study that was a precursor to SHRP had already investigated density gradients in laboratory-compacted and in field-compacted mixtures. The

AAMAS study evaluated several different laboratory compactors. NCHRP 9-6(1) did field studies in Colorado, Michigan, Texas, Virginia and Wyoming in which mixture compaction on the road was monitored and loose mix samples were collected and compacted in several different laboratory compactors. Air voids were measured on cores taken from the road and on laboratory-compacted specimens. Next, the cores or lab-compacted specimens were sawn horizontally into three disks. Air voids were measured in the top, middle and bottom. The difference between the lowest air void piece and the highest air void piece was defined as the density gradient.

Table 7 shows the difference in air voids of the middle slice compared to the highest air void slice. The same information is also shown for the Texas Gyratory Shear Compactor (the standard TxDOT design, not the modified version used during SHRP). For both the laboratory specimens and the field cores, the middle third always had lower air voids. About half the time the top slice had the highest air voids. The rest of the time, the bottom slice had the highest air voids.

Table 7 NCHRP 9-6(1) AAMAS Comparison of Air Void Gradient (Difference between Middle of Specimen and Lowest Third) (*11*)

Air Void Difference between Lowest and Highest Third of Specimen		
Project Location	Field Core	Texas Gyratory
Colorado	1.79	1.35
Michigan	0.94	.89
Texas	2.15	1.71
Virginia	2.13	1.52
Wyoming	2.04	1.88
Average	1.81	1.53

Knowing that density gradients occur in both field-compacted and laboratory-compacted specimens, a study was done during SHRP to evaluate density gradients in the Superpave gyratory compactor. Specimens were compacted in the prototype Superpave gyratory compactor then were sawed and cored. Figure 34 shows a core with a height to diameter ratio of 0.75. It is a mix design done with one of the SHRP aggregates, RL, compacted to approximately 7% air voids.

Air void measurements of the different pieces are shown in Table 8. Air voids of the uncut specimen were 6.8%. The top slice has the highest air voids at 7.4%, which is 1.5% higher than air voids of the middle slice. Note that air voids of the outside ring are 7.5%, 2% higher than the inside ring or the center. Together the inside ring and the center have a consistent air void content. The maximum difference in density from the top outside ring to the center is 4%. Based on this experiment, the height to diameter ratio was selected to be 0.75, which for 150 mm diameter means the height would be 112.5 mm. Ultimately the specimen height in AASHTO TP 4 (later AASHTO M 312) was set at 115 ± 5 mm.

Figure 34 Gyratory Specimens Sliced and Cored for Density Gradient Analysis

Table 8 Density Gradient in Specimen Compacted on Prototype Gyratory Compactor (*14*)

	Outside Ring	Inside Ring	Center	Inside Ring	Outside Ring	Average
Top Slice	8%	6.5%	6%	6.5%	8%	7.4%
Middle Slice	7%	4%	4%	4%	7%	5.9%
Bottom Slice	7.5%	6%	6½%	6%	7.5%	7.0%
Average	7.5%	5.5%	5.5%	5.5%	7.5%	6.8%

4.5.5.5 Field Compaction of Superpave Mixes

Early in Superpave implementation there were some issues with achieving density, especially in areas where the Marshall mixes had been easy to compact. Some people investigated Superpave mix compactability by compacting gyratory specimens equal to the lift thickness. So, for example, a 12.5-mm mixture would be compacted 40 mm (1½ inches) tall and the density was found to be much lower than a specimen compacted 115 mm tall.

This led to a debate at the Asphalt Mixture Expert Task Group. The point being debated was whether specimen height should be the same as lift thickness. The issue is that compaction efficiency in the mold is more sensitive than in the field. There is a wider range of lift thicknesses that can be used successfully in the field as long as the lift thickness is not too thin.

In the gyratory mold, a change in specimen height means a change in the zone of disturbance and a different compaction efficiency. As a result, the decision was made to keep the compaction efficiency in the mold the same for all mixtures (i.e., to keep the height to diameter ratio the same).

During early implementation, field compaction problems became apparent when lifts were too thin. As a result of Florida DOT experience, the recommended minimum lift thickness was set based on the nominal maximum size of the mixture. The desirable lift thickness for coarse-graded mixtures was set at 4 to 6 times the nominal maximum aggregate size (NMAS). For fine-graded mixtures, the desirable lift thickness was set at 3 to 6 times the NMAS.

4.5.5.6 The Corps of Engineers Gyratory Test Machine

A significant debate occurred during the latter part of the SHRP Program and continued on for several years afterward. The manufacturer of the gyratory test machine (GTM) believed the SHRP researchers were speaking of the GTM when they talked about gyratory compaction. When they discovered that it was not the GTM being considered, a campaign was started to change the recommendation. This raises the question of what is behind the story and why the gyratory test machine was not selected.

As discussed earlier a study of laboratory compaction occurred during the NCHRP 9-6 project. For gyratory compaction, the investigators used the Texas 4-inch Gyratory Shear Compactor in that study. The Gyratory Shear Compactor was identified as best simulating field compaction based on mechanical properties of laboratory-compacted specimens and aggregate orientation in the specimens. It was on the basis of this study that gyratory compaction was selected as the preferred method and a Superpave gyratory compaction protocol was developed. In the conclusions of the NCHRP 9-6 report, the Texas Gyratory Shear Compactor was recommended as being the best for field compaction simulation (*11*).

Also as part of the NCHRP 9-6 study, cores were taken from the field projects for a period of two years and the change in density from traffic loading was monitored. The GTM was used to evaluate densification under traffic. The final NCHRP 9-6 report contained recommendations about the need for continued research into the GTM. The following paragraph is from Section 4.3 (*11*).

> <u>Uncommon Tests</u> *Gyratory shear strength or the use of the Corps of Engineers GTM was found to provide a reasonable evaluation of asphalt concrete mixtures that were known to be "sensitive" mixtures or mixtures that are susceptible to a reduction in shear strength with traffic. However, this parameter is not used in any mechanistic model nor is it commonly used to evaluate mixtures. Thus, additional mixtures should be evaluated and designed with the GTM and then monitored to gain the critical performance data to validate its results.*

The GTM manufacturer believed that the 9-6 report recommended use of rather than further research on the Corps of Engineers machine. In the summer of 1991, as the SHRP work was progressing with the modified Texas 6-inch gyratory compactor, the GTM inventor, John McRae, realized that his machine was no longer being considered as a compactor for Superpave, which led to debates paraphrased as follows:

- "My machine can do everything you are trying to do in SHRP."

- “You mean it can predict rutting and cracking?”
- “Well, you are trying to design pavements that don’t rut. It doesn’t matter about predicting how much rutting there is. You just don’t want any rutting to occur and my machine can design mixes that don’t rut.”
- “No. Performance prediction is our objective. Other contracts are evaluating mixture properties and performance prediction.”
- “My machine measures fundamental engineering properties.”
- “What about compaction? Would you make your machine a compactor? What would you change? And how much less would it cost?”
- “No, the GTM cannot be changed. The price would stay the same.”
- “But currently it is a laboratory machine. It should be made smaller since it has to be used in the field for QC.”
- “No it doesn’t need to be smaller; I can make it portable.”

And so the conversation went over the course of several months.

In response to the interaction, McRae outfitted a GTM with a computer to capture the information as a replacement to the x-y paper plotter that had been used until then. Also, a GTM was mounted in a trailer to demonstrate that the machine was portable.

On March 9, 1992, an open house was hosted by the Corps of Engineers to demonstrate the updated equipment. The open house, not held specifically for SHRP, was attended by about 25 representatives from different parts of the asphalt industry. In discussions about the updated equipment it was clear that the inventor strongly believed in the ability of his machine to design an asphalt mixture that would not rut. But, it also was clear that he did not understand the goals and objectives of the SHRP Asphalt Program nor how his compactor would fit into those objectives. He was adamant that the researchers were ignoring the results of the NCHRP 9-6 study and that he was being discriminated against.

After review of the situation, Damian Kulash, SHRP Director, asked for a meeting to review the pertinent facts and to hear discussion regarding applicability of the GTM to the goals of the Asphalt Research Program. On April 16, 1992, a meeting was held at the SHRP offices in Washington, DC. It was attended by John McRae and his son John McRae Jr. representing the Engineering Development Company. SHRP was represented by Kulash and Ed Harrigan, the Asphalt Program Manager. The researchers were represented by Tom Kennedy, Technical Director of the Asphalt Program, Gerry Huber of the A-001 contract and Carl Monismith (by phone) of the A-003A contract.

The discussion was primarily technical with Professor Monismith debating the technical analysis provided by McRae. In the end, the SHRP staff considered the points being made by the researchers and the GTM inventor. Kulash agreed that the case for the GTM was not compelling and it was removed from further consideration.

The rejection only served to strengthen the resolve of the inventor. The campaign became grass roots with packages of technical data and arguments – the same ones aired at the meeting with SHRP – being mailed to various researchers and DOT people in the country along with requests for support in helping SHRP realize the error they were making.

At one point after the end of SHRP, a senator from Mississippi intervened on behalf of the GTM inventor. FHWA was asked to support its decision to implement Superpave without the GTM and defend against the accusation that a federal agency was acting in restraint of domestic trade in preference to foreign (French) technology. Ultimately, that defense was made.

Discussion of the GTM waned and implementation of the Superpave gyratory compactor continued.

4.5.5.7 Rolling Wheel Compaction

A significant debate occurred within the SHRP Asphalt Research team about using a rolling wheel compactor, such as that shown in Figure 35, as the laboratory compaction method. This discussion originated from the A-003A contract and overshadowed research activities for an extended period of time.

The A-003A contract was awarded in the fall of 1988, and work started shortly thereafter. One of the early studies was an experiment to investigate the effect of compaction method on mechanical properties of HMA. The NCHRP 9-6 study had looked at several laboratory compaction methods and had made recommendations that the gyratory compactor appeared to be the best as compared to field-compacted mixtures. Rolling wheel simulation and kneading compaction also compared quite well.

The A-003A study focused on Texas gyratory compaction, kneading compaction (used in the Hveem mix design method) and rolling wheel compaction. A large experiment was done that included two mix designs with two different asphalt binders. Specimens were tested at design air voids and high air voids. A low and a high asphalt content were used; the low value was obtained by Hveem design and the high value by Marshall design. The main effects studied were rutting and fatigue resistance.

Figure 35 Students Compacting a Specimen by Rolling Wheel at University of California Berkeley, April 1991 (All persons are unidentified)

Generally the experiment showed that gyratory specimens had a weaker aggregate skeleton leading to poorer rut resistance and better fatigue properties. At the other end of the scale were kneading compacted specimens, which had the strongest aggregate structure. Kneading compacted specimens had the best rut resistance and the poorest fatigue resistance. Rolling wheel compacted specimens were somewhere between.

Before continuing discussion about the type of compaction, it is important to understand the thought process in place in 1991 when the compaction experiment was completed. At the beginning of SHRP, the vision for mix design was a new method where properties of candidate mixtures would be measured and performance would be predicted. Today, in the current Mechanistic-Empirical Pavement Design Guide, this is the process that is used to design structural thickness. In 1991, the thought was to design mixtures based on predicted performance. And so, gone would be the days of air voids and VMA and other such empirical properties. In their place would be performance-based properties that would be used in determining an acceptable mix design.

In January 1991, the A-001 team conceived the idea of different levels of mix designs where the base level design would be a volumetric design. However, the idea of predicting performance was still considered to be the ultimate goal. Based on results of the compaction experiment the A-003A team began a concerted campaign to have rolling wheel compaction adopted as the compaction method for the new mix design method.

The A-003A team developed a draft specification that called for compacting 7 kg of mix in a mold 24 inches by 24 inches by 3 inches deep. The mixture was to be mixed then cured for 15 hours overnight at 60ºC, heated for an hour and a half to compaction temperature, then compacted. After compaction the mix was to remain in the mold and be cooled overnight. The next day it would be cored and cut for testing, as diagrammed in Figure 36. The net effect was a three day process to mix and compact specimens.

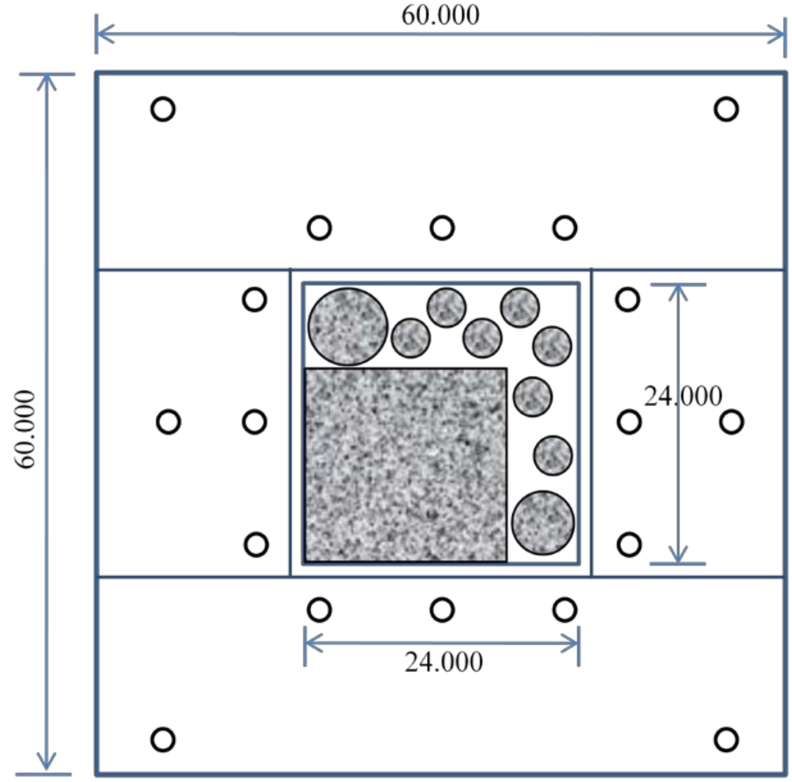


Figure 36 A-003A Proposed Sawing and Coring of Slab for Rolling Wheel Compacted Specimen. (Slab is in the center of the square) (*12*)

The view of the A-001 team was that rolling wheel compaction was impractical for use in mix design. Although the gyratory-compacted specimens might not have exactly the same properties as rolling wheel compacted specimens, evaluation of compacted mixture gave the same trends for both. To demonstrate that their results could be applied beyond their laboratory experiment the A-003A team compared the properties of lab-compacted mix from two projects in California. Both projects had properties that best correlated with rolling wheel compacted specimens. This further enhanced the case for rolling wheel compaction.

Seeking support outside the SHRP community, the A-003A team hosted an open house with representatives from NAPA. The case for using rolling wheel compaction was presented. To allay fears of the difficulty of using rolling wheel compaction, the method of specimen preparation was presented. The argument was presented that instead of producing many specimens for the different types of testing, one compacted slab could provide all the necessary specimens for rut resistance, fatigue resistance and low-temperature cracking. Eight fatigue beams, seven 4-inch cores and two 6-inch cores could be obtained from the single slab, as shown in Figure 36.

The reaction of the contracting community was negative. Contractors were used to compacting three 4-inch Marshall specimens on a $1,500 compactor and were already balking at the idea of a $20,000 gyratory compactor to produce 6-inch specimens. The rolling wheel proposal looked even less attractive.

In response, the A-001 contractor commissioned the A-005 team at Texas A&M University to perform a study of compaction. The focus of this study was narrower than the A-003A study. Cores were obtained from five different pavement sections. Some of the cores were tested directly and some were re-heated and compacted using Texas gyratory, rotating base Marshall hammer, Exxon rolling wheel simulator and the ELF linear kneading compactor. Measured properties of the cores and the compacted specimens included stiffness at two temperatures, repeated loading creep and stability (by Marshall and Hveem methods). The properties of specimens prepared with the gyratory compactor were found to be equivalent to those of the cores in 24 of 33 comparisons. The Exxon rolling wheel simulator was equivalent in 19 of 32 comparisons. This data supported the A-001 position that gyratory compaction was at least as good as, maybe better than, a rolling wheel compactor. This study was completed in the spring of 1992 (*14*).

In effect, the thought of the A-001 contractor was that NCHRP 9-6 had answered the question of which compactor should be used. This Texas A&M study was a supplement that supported the NCHRP 9-6 study. On the other hand, the A-003A contractor viewed the report as an indicator of doubt about the goodness of the data developed at UC-Berkeley.

The debate about the compaction method went on for a long time. In June 1992, more than a year after the discussion started, there was a proposal to construct a 1000 foot long test section using SHRP aggregate RB (one of the same used in the A-003A experiment) to again compare the different laboratory compaction methods with field compaction. The proposal was not acted upon.

All of this contributed to a strained relationship between the A-001 and A-003A research teams. One thought the other was refusing to acknowledge reasonable engineering results. The other thought the first was fixated on technical details without considering practicality.

And so, the debate continued. Considerable energy and expense were expended as a result. Perhaps, in retrospect, it should have been recognized at the beginning of SHRP that laboratory compaction still had several unanswered questions and that a study was required with a larger scope than the A-003A experiment.

In the end, it probably doesn't matter who was right, A-001 or A-003A (or both, or neither). Performance prediction as envisioned for Superpave never came to fruition. Only after many more years of research sponsored by the FHWA and NCHRP – and in particular the development of the Mechanistic-Empirical Pavement Design Guide (MEPDG), the Asphalt Mix Performance Tester and supporting test methods – did a systematic method for performance prediction come into being. In retrospect, the approach envisioned for Superpave might have been successful had there been a strong champion for the approach and resources to fund more development of the models and revision of the software. Because of the lack of agreement between the researchers, there was no champion for this effort. The Superpave version implemented at the end of SHRP was a volumetric mix design method rooted in empirical properties of the past. Gyratory compaction works just fine for that.

Also, A-001 selected a different gyratory angle. The Texas gyratory used in the A-003A experiment and the NCHRP 9-6 study had a nominal 6° angle. SHRP ended up selecting 1.25° as the angle of gyration. The effect of this change in angle on mechanical properties of the mixture was not investigated as part of SHRP.

A few months after SHRP ended, in June 1993, the Asphalt Institute conducted a mix design for an SPS-9 section in Arizona. The new tests proposed by A-003A were performed on the gyratory-compacted specimens and something unexpected was discovered. In the A-003A work, gyratory-compacted specimens were shown to have lower stiffness and less rutting resistance than roller compacted specimens. In the Arizona SPS-9 section, specimens compacted by the Asphalt Institute with the new SHRP gyratory compactor were found to have higher stiffness and rut resistance. Properties of gyratory specimens compacted with the 1.25° angle were different than ones compacted with an angle of 6°. This fact remained undiscovered during SHRP.

The reason for the change in mechanical properties with the change in angle was never fully answered. Subsequent research by FHWA and NCHRP found that even small changes in the angle—on the order of several tenths of degree—can have substantial effects on both compaction and mechanical properties. Various hypotheses have been put forward, but the cause of these effects is not well understood, even to this day.

4.5.6 The Delphi Story

Early on in the Asphalt Research Program, the emphasis was on asphalt binder research. The A-002 projects were concerned with asphalt binder properties and what could be done differently than in the past. Much of the emphasis was on asphalt chemistry, and it was envisioned that the new specification would be a chemical specification. At the same time, many exotic technologies were being explored, such as acoustic emissions from the poker chip test.

The first asphalt binder contract (A-002A), let in the second quarter of 1988, was tasked with identifying binder properties that influenced mix behavior. In the last quarter of 1988, the first asphalt mixture contract was let. This contract was tasked with validating that asphalt binder properties did influence mixture behavior. Also, it was tasked with developing mixture evaluation tests that could be used to measure fundamental engineering properties.

A fundamental engineering property was defined as a property that could be used to predict a material's response to stresses or strains. For example, if asphalt mixture was an elastic material, then modulus could be measured and strain could be calculated for any imposed load.

Modulus would be the fundamental engineering property. Unfortunately, the behavior of HMA is more complicated, and, depending on the temperature and the time of load, its behavior may be linear elastic, non-linear elastic, visco-plastic, or plastic. To predict stress or strain in HMA required a material property model that encompassed all of the above.

In the last quarter of 1989, Contract A-005 was let. This contract was tasked with developing performance prediction models that would convert stress and strain imposed on the asphalt mixture to expected performance such as rutting, fatigue cracking and low-temperature cracking. So, for example, for an amount of stress or strain imposed on the HMA, the amount of fatigue damage or the amount of non-recoverable deformation (rutting) would be calculated.

Throughout 1989 and 1990, work progressed on the validation of properties and development of tests. In the third quarter of 1990, contract A-006 was awarded. This contract was tasked with developing a mix design system using the asphalt binder specification, asphalt mixture tests and asphalt mixture performance models.

The first official meeting of the A-006 contract occurred in September 1990. Up until that time, the vision of the new mix design system was very different than what we have today. Then it was envisioned that the mixture tests and performance models that were being developed would give performance predictions and candidate mixtures would be selected based on their predicted performance. Such things as gradation, air voids, VMA, even asphalt binder content, were considered to be concepts of the past. True, it was recognized, as had been in the past, that engineering properties of the mixture were influenced by these volumetric properties. But the vision was to use the new properties to predict performance directly.

Perhaps the goal was too large. Perhaps the complexity was underestimated. Perhaps the focus on asphalt binder had reduced proper consideration being given to asphalt mixture. But in the fall of 1990 when the A-006 project commenced, there was some discussion of the old properties.

By January 1991, it became clear that the mixture tests and the mixture performance prediction models were going to be much more complicated than anticipated. Work on the tests and models continued, and the final outcome was not yet known, but as the research continued, one thing was clear; it would not make sense to use this system for all mix designs.

A graduated mix design system was needed. The full-blown performance prediction made sense for high volume, high-cost projects. For others it did not. And so, the concept of Level 1, Level 2 and Level 3 mix designs was formed.

Level 3 mix design would use the entire spectrum of tests to measure mixture properties and mixture performance. Level 2 would be either a simplified version of Level 3 with a performance prediction or it would be a torture test. One such torture test discussed was wheel track rut-testers. Following the European Asphalt Study Tour (EAST), a delegation of senior FHWA, state DOT and industry association personnel returned with information on the French LCPC wheel track tester and proposed it or similar wheel-tracking equipment as a performance test (*15*).

Level 1 mix design was to be based on the old volumetric mixture properties. Such was the necessity of developing a workable system. However, the problem facing A-001 was there was no time or funding available for research on:

- the proper level of air voids,
- how VMA should be calculated, and
- how gradation should be specified.

The old properties were needed. The question was "How to get them?" A study of state DOT specifications indicated that there was no consensus, at least in what was being done. And so, the decision was made to use the Delphi method.

4.5.6.1 The Delphi Method

The Delphi method is a process for developing consensus among a group of experts. It requires that the experts have a working knowledge of the area of study. The method does not use debate; that is, experts do not debate who is right and who is wrong regarding some property. Instead, the experts are given a series of questionnaires. The first questionnaire defines the area to be investigated.

So, on a scale of very strongly disagree, strongly disagree, disagree, neutral, agree, strongly agree and very strongly agree, the participants indicated the relative importance of a property in the mix design system in the first questionnaire. For example, they would react to the statement "Design air voids should be part of the mix design".

There were seven aggregate properties and three mixture properties considered:

- gradation limits
- crushed faces
- natural sand content
- LA abrasion
- soundness
- deleterious content
- sand equivalent
- air voids
- VMA
- Voids filled with asphalt

Also on Questionnaire 1 there was a set of follow-up questions for each property:

- What is the best way to measure the property (say air voids, for example)?
- Are there any external influences that would change the level of air voids used?
- How does that factor affect air voids?

Fourteen experts were selected who represented a balance of state DOTs, industry representatives (NAPA, NCAT, National Aggregates Association and contractors), and university researchers. They received the questionnaire by mail. After the first questionnaire, all of the remaining questionnaires and decision-making happened in a two-day meeting attended by the fourteen experts.

After the first questionnaire results were received, the panel members were brought together and the results were presented and discussed. Questionnaire 2 included a shortened version of the first questionnaire, including only the strongly disagree to strongly agree scale about the properties being included in a mix design specification. This was done to see if the discussion influenced their opinion.

The second part of Questionnaire 2 included a series of eight scenarios that had been statistically designed. The scenarios described highways that had different traffic, pavement thickness, climate, etc. The participants were asked to give their best judgment of what the specification limit should be for the property. The highway locations included different:

- precipitation levels,
- July temperature,
- coldest winter temperature,
- traffic level and
- depth from the pavement surface.

The results from the second questionnaire were tabulated and discussed. A third questionnaire was designed overnight and given to the group the next morning.

By the end of the third questionnaire, it was clear which properties the group felt were important. Some of the properties changed during the discussion. For example, percent natural sand was dropped and fine aggregate angularity took its place. In the fourth questionnaire, participants were asked to rank each property as to its importance for performance. The fifth and final questionnaire was given. It built upon the previous scenarios and was used to estimate specification limits.

In the end, it was possible to determine what properties should be used, under what circumstances they should be adjusted and what the specification limits should be. Some properties did not change with changes in condition. For example, for low traffic pavements, air voids were suggested to be between to be between 3.4 and 4.9%. For high traffic pavements the range was 3.5 to 4.9%. On the other hand, the average for crushed faces was 67% for low traffic and 84% for high traffic.

Some of the properties had a low probability of error, less than one percent, meaning that the experts were in close agreement. The properties with higher error, 5%, tended to be properties on which the group was polarized and could not reach as good a consensus.

In the end, it was decided to call toughness, soundness and deleterious content agency or source properties. The other properties became known as consensus properties because a consensus had been reached. These included:

- gradation,
- coarse aggregate angularity,
- fine aggregate angularity,
- flat and elongated particle content
- clay content (sand equivalent),
- air voids,
- voids in mineral aggregate and
- voids filled with asphalt.

Although consensus was reached on these properties, it does not mean that everyone agreed. For example, one of the most contentious discussions was the calculation of VMA. One part of the group felt that aggregate bulk specific gravity (G_{sb}) should be used. The rest felt that effective specific gravity (G_{se}) was the correct way because "it represented the true volume of rock in asphalt" and was more easily measured than G_{sb}, especially for absorptive aggregates. The group remained polarized. Finally the discussion was settled with a discussion of absorption.

For states that used G_{se}, the question of how to account for absorbed asphalt was discussed. For aggregates with significant absorption (typically considered to be greater than 2% water absorption), the amount of absorbed asphalt must be accounted for. This correction required G_{sb} to be measured – a worst case situation since measurement on absorptive aggregate is more variable. Therefore, the group consensus was to use G_{sb} for all aggregates, absorptive and non-absorptive alike.

Interestingly, this exercise occurred during SHRP. Years later, NCHRP research projects were conducted looking at air voids and VMA. The findings of the NCHRP researchers were based on laboratory test data, not opinions. They found that that the values from the Delphi group in AASHTO M 323 were reasonable and no changes were recommended.

As the recommendations from SHRP became known, state DOT engineers considered how to reconcile the findings with their existing specifications. In response to an inquiry from Dave Esch, of the Alaska DOT, the following letter was drafted on February 24, 1993, to explain the basis of the recommendations on gradation. This letter illustrates the types of discussions that were occurring at the time.

February 24, 1993

Dear Dave,

You raise some interesting points which will be expressed again by others in the future. First of all, let me reassure you that the SHRP team gave careful consideration to the selection of gradation controls. Second, it is not always possible to exchange existing gradation controls one for one with the new SHRP gradation bands. Such is your case in Alaska.

Let me explain the rationale used to set SHRP gradation controls. Maximum density lines are not specifically part of the SHRP specs although the controls are built around them and maximum density lines are shown on figures. The most definitive work done on maximum density lines and nominal maximum size is contained in an ASTM paper from the Asphalt Institute. The Asphalt Institute built upon the work of Goode and Lufsey from the Bureau of Public Roads published in AAPT in 1962. The new proposed definition of nominal maximum size and drawing of maximum density lines provided an explanation for some "anomalies" identified by Goode and Lufsey. Incidentally, the definition of nominal maximum size is a more specific interpretation of the ASTM definition.

SHRP's adoption of nominal maximum size and maximum density line is supported by independent adoption by the FHWA. An FHWA Expert Task Group on Volumetric Properties debated the issues at length and considered all available information. Opinions of the ETG were not unanimous; in particular, some views wanted the "max density line" drawn to the actual percent minus 200. A review by the ETG supported adoption of the Asphalt Institute (method).

Next, consider the restricted zone. SHRP had opted to specify mixtures with distinct coarse aggregate skeletons in line with the philosophy of European mix designs. European porous asphalt has a coarse aggregate skeleton with 20% air voids. European SMA mixtures use the same coarse aggregate skeleton filled with a bitumen:filler mastic. SHRP desired to specify dense-graded mixtures with a coarse aggregate skeleton and sand asphalt occupying the space within the skeleton.

Examination of the attached SHRP gradation controls illustrates the role of the restricted zone in accomplishing the desired mixture. A gradation below the restricted zone must pass above the minimum % passing 2.36 mm (#8) sieve and not enter the restricted zone. To meet VMA requirements several coarse aggregate gradations can be evaluated. Regardless of coarse aggregate gradations, fine aggregate gradation cannot change significantly. In other words, VMA is obtained in SHRP mixtures by changing the coarse aggregate skeleton. The "filling" in the skeleton is sand asphalt.

Now let me consider the case you present in your letter. First, notice the wide boundaries in Alaska's specification. The fine aggregate portion can vary greatly producing very "sandy" mixtures or very coarse mixtures. Indeed the specification band is so wide as to allow significantly different mixtures to be produced, mixtures which would be categorized as two different SHRP mixtures. The broadness of Alaska's specification is specifically the reason why it cannot be replaced with a single SHRP gradation control.

To combat the problems of very wide gradation bands some other states have tried to narrow the range of acceptable gradations making for "tight" gradation specs. Unfortunately, it can be difficult or impossible to achieve adequate VMA.

The SHRP gradation controls solve the problem of wide gradation bands without the dilemma of narrow bands. SHRP gradation controls are "narrow" enough to specify mixtures which will meet only one nominal maximum size and at the same time are "wide" enough achieve required VMA levels by building a coarse aggregate skeleton.

I hope the above explanation gives you some insight into the logic of SHRP gradation bands. I know that the SHRP gradation controls are significantly different than some existing specifications as you point out and states will be faced with change during the implementation process. We will be faced with many changes originating from the SHRP research. It is my belief that many changes will be justified by benefits received. Gradation controls are a change which is justified.

Sincerely,
Ed Harrigan

cc: H. Tahir

4.5.7 Products from Studies of Moisture Damage: NAT and AASHTO T 283

In addition to the mix design procedure, the SHRP Asphalt Research program led to the development of some additional mix related products. Some of the most notable of these dealt with the question of moisture damage in asphalt pavements.

Although many factors contribute to the degradation of asphalt concrete pavement, damage caused by moisture was considered (and remains) a key element in the deterioration of asphalt mixes. Most of the early research, in the late 1930s and early 1940s focused on adhesive failure or stripping rather than cohesive failure. In the 1950s, the immersion-compression test, later adopted as an ASTM standard, was developed to evaluate the moisture sensitivity of compacted asphalt mixes. Also in this decade, researchers concluded that the rate at which stripping occurs depends upon the surface energy of the materials involved. A sonic test to evaluate stripping resistance was introduced. In the early 1960s, Caltrans engineers observed "serious pavement failures … with little evidence of internal stripping," thus recognizing cohesive failure in the binder as a moisture damage issue. In 1970s, resilient modulus testing was used to show the cycling effect moisture has on asphalt mix stiffness. Other research in the 1970s captured the detrimental effects of water and freeze-thaw cycling and led to the development of a test which measures the retained strength of asphalt compacted cores subjected to defined exposure conditions. This test, commonly known as the "modified Lottman," was standardized and adopted as AASHTO T 283. It is still widely used today to measure the resistance of compacted asphalt mixes to moisture induced damage. In fact, AASHTO T 283 was integrated in the Superpave mix design system. Research in the 1980s focused on the evaluation of anti-strip additives. Also in this decade, additional tests were introduced: the boiling water, freeze-thaw pedestal and bonding energy tests.

The next major contribution to research on moisture sensitivity of asphalt mixes emerged as a result of the SHRP Asphalt Program. As noted previously, a major goal of SHRP was to relate asphalt binder properties to field performance of asphalt concrete mixes.

There are three mechanisms by which moisture can degrade the integrity of an asphalt concrete matrix: (1) loss of cohesion (strength) and stiffness of the asphalt film that may be due to several mechanisms; (2) failure of the adhesion (bond) between the aggregate and asphalt (often called *stripping*), and (3) degradation or fracture of the aggregate, particularly when the mix is subjected to freezing. Research on these mechanisms was addressed in two major contracts: A003A and A003B. The focus of the former was to define water sensitivity of asphalt concrete mixes with respect to performance, including fatigue, rutting, and thermal cracking, and (2) to develop laboratory testing procedures that would predict field performance. The latter examined the chemistry and physics of the asphalt-aggregate bond with emphasis on adhesion and absorption properties. Key products of these studies, the net adsorption test (NAT) and Environmental Conditioning System (ECS), are addressed in the following narrative.

4.5.7.1 Net Adsorption Test

The overall objective of the A-003B contractor was to investigate and understand fundamental aspects of asphalt-aggregate interactions including both chemical and physical processes. The critical phenomena explored were adhesion and absorption. A key product that emerged from this research was the net adsorption test (NAT).

The NAT provides a method for selecting asphalt-aggregate pairs and determining their compatibility. The test is composed of two steps. First, asphalt is adsorbed onto aggregate from a toluene solution, the amount of asphalt remaining in solution is measured, and the amount of asphalt adsorbed to the aggregate is calculated by difference. Second, water is introduced into the system, asphalt is desorbed from the aggregate surface, the asphalt present in the solution is measured, and the amount remaining on the aggregate surface is calculated. The amount of asphalt remaining on the surface after the desorption step is termed net adsorption.

The development of the test occurred in two steps: first, an initial screening of MRL aggregates (both siliceous and calcareous) was performed with three different MRL asphalts. The initial testing used 5 grams of -40 to +80 (passing the #40 sieve and retained on the #80 sieve) mesh washed aggregates. Second, a scaled-up version of the test was developed by the University of Nevada Reno. This somewhat refined procedure, as outlined in SHRPT Test M-001, employed a sample size of 50 grams of -#4-fraction of unwashed aggregate and commercially available equipment. The researchers recommended the criteria shown in Table 9 and concluded that the interactions between asphalt and aggregate were dominated by aggregate chemistry. Asphalt chemistry also had an influence, though much smaller than that of the aggregate.

Table 9 Recommended NAT Criteria

Net Adsorption(%)	Moisture Sensitivity of Asphalt-Aggregate Pair
>70	Acceptable
55 – 69	Marginal
<55	Poor

Although the NAT was considered an effective screening test (i.e., an indicator of adhesion), it did not consider the cohesion-loss mechanism of water damage. Hence, even acceptable test results did not obviate the need for testing the compacted mix. Other likely reasons for its lack of use include the following: The test procedure requires about 8.5 hours. The fact that it was “optional” in the originally configured Superpave mix design system, and hence, not part of the FHWA’s pooled-fund equipment purchase may also have contributed to its premature demise.

4.5.7.2 ECS vs. AASHTO T283

As noted in Section 4.5.7, the development of tests to determine the water sensitivity of asphalt concrete mixes began in the 1930s. Since then, numerous tests had been (and continue to be) developed in an attempt to identify asphalt concrete mixes susceptible to water damage. However, at the onset of SHRP, none had emerged as acceptable over a wide range of conditions or materials, and none were performance-related.

A-003A contract researchers had hypothesized that much of the water damage in pavements was caused by water in the void system; i.e., that most of the water damaged occurred when the void content was in the range typically usually used in construction of dense-graded mixes, about 5 to 12 percent. Furthermore, the researchers noted that although the terms *moisture* and *water* were often used interchangeably, there appeared to be a difference between the actions of moisture vapor and liquid water in distress mechanisms such as stripping.

To evaluate this hypothesis and the numerous variables affecting water sensitivity, the Environmental Conditioning System (ECS) was designed and fabricated. The ECS consisted of three subsystems: (1) fluid conditioning, in which the specimen is subjected to predetermined levels of water, air, or vapor, and permeability is measured; (2) an environmental chamber that controls the temperature and humidity and encloses the entire loading frame; and (3) the loading system that determines resilient modulus at various times during environmental cycling and also provides continuous repeated loading as needed.

The ECS procedure that emerged at the conclusion of the research required testing of cylindrical specimens (4 inches in diameter by 4 inches in height) for six-hour cycles of wet-hot (140ºF) and wet-freeze (-40ºF) while resilient modulus was monitored before and between cycling at 77ºF.

The researchers demonstrated that the ECS was capable of discerning the relative differences in performance, as measured by resilient modulus. In addition, the temperature cycling and repeated loading used in the ECS provided a good indicator of long-term mix performance. The ECS test method provided a number of parameters from the tested specimen (e.g., retained resilient modulus, permeability, *s*tripping rate), and stress-strain information at different temperatures during conditioning, through the data-acquisition capability of the system. Finally, the test results suggested that the ECS had better repeatability and required fewer specimens than the widely used AASHTO T 283. Advantages of the ECS cited by the researchers included the following:

- permeability monitoring after each conditioning cycle;
- reduced variability because of only one specimen set-up; and
- application of repeated load throughout the test.

Despite the fact that the ECS test results showed reasonable correlation with field performance, it was not included in the Superpave mix design system. Why? The reasons were twofold: equipment cost and specimen configuration. The benefits of the ECS were not deemed sufficient to outweigh the additional cost, at that time estimated to be about $70,000. Decision-makers were concerned that state DOTs, already burdened with purchasing the required binder equipment and the gyratory compactor – the minimum needed to transition from Marshall or Hveem to Superpave – would be reluctant to expend additional funds. Furthermore, most state DOTs were familiar with T 283 or some variation thereof. Finally, for volumetric mix design (Superpave Level 1), gyratory-compacted specimens would be 150mm in diameter. An obvious and expensive question was, how could this mesh with the ECS recommended specimen configuration? Despite its advantages – better repeatability and fewer specimens than the widely used AASHTO T 283 – and the fact that it yielded an indicator of performance, as measures by resilient modulus, it was not adopted.

4.5.8 Analysis of a Meeting

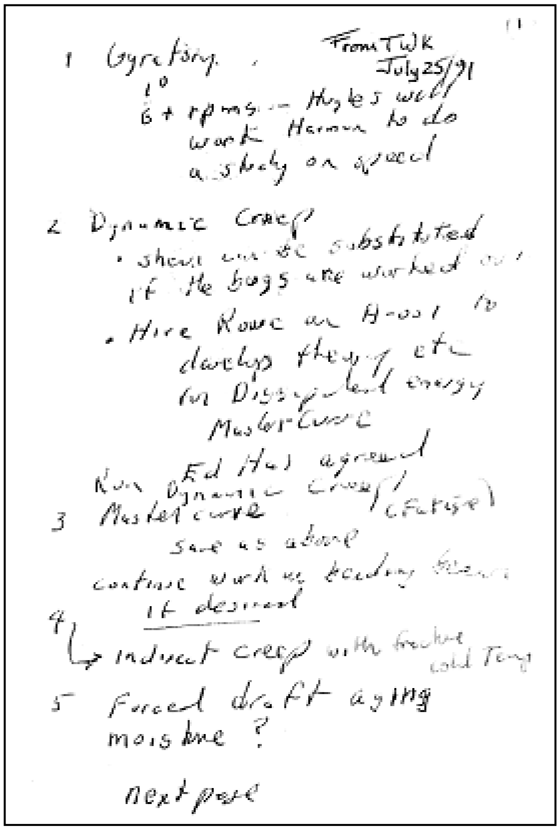
The SHRP Asphalt Research Program was a high pressure experience for the participants. A meeting held on July 25, 1991 at the Green Building (National Academy of Sciences at 2001 Wisconsin Ave NW) provides an insight into the pressure and its effect on the people involved.

This meeting was one of the regularly scheduled contractor meetings at which the researchers from various projects met to discuss experiments and data. These meetings also provided the A-001 team with an opportunity to review the direction of research and make decisions about what should be done next.

Relations between Professor Carl Monismith, head of the A-003A contract, Dr. Bob Lytton, head of the A-005 contract, and Dr. Tom Kennedy, head of the A-001 contract, had been growing more strained over the past few months. One issue was the competing ideas from the A-003A and A-005 teams over models to be used. The main purpose of this meeting was to have the groups present their ideas and make a decision about which direction to go.

Bob Lytton had made a presentation about the models proposed by the A-005 team and experiments proposed to investigate them. Dr. Jim Rosenberger, a statistician from Penn State University on the A-001 team, was critiquing the proposal, and the conversation was becoming heated. The emotion and intensity in the room had grown to a breaking point. It culminated with Bob Lytton giving a treatise on Sir Isaac Newton's development of his model of F=ma. The lecture continued into the lack of innovation in America and the resultant growing trade imbalance with Japan. At this point Mr. Jim Moulthrop of the A-001 team suggested the group take a 10 minute break.

As the discussion had degenerated Tom Kennedy sat at the table and made notes on a folded piece of copy paper. During the break he made copies of it and handed it out to members of the A-001 team charged with pulling together a mix design system from the research being done. A copy of the notes is shown in Figure 1. First he laid out the status of the development of a mix analysis method. Then he laid out a plan for what needed to be done.



Page 1

1. Gyratory
   - 1°
   - 6 rpms

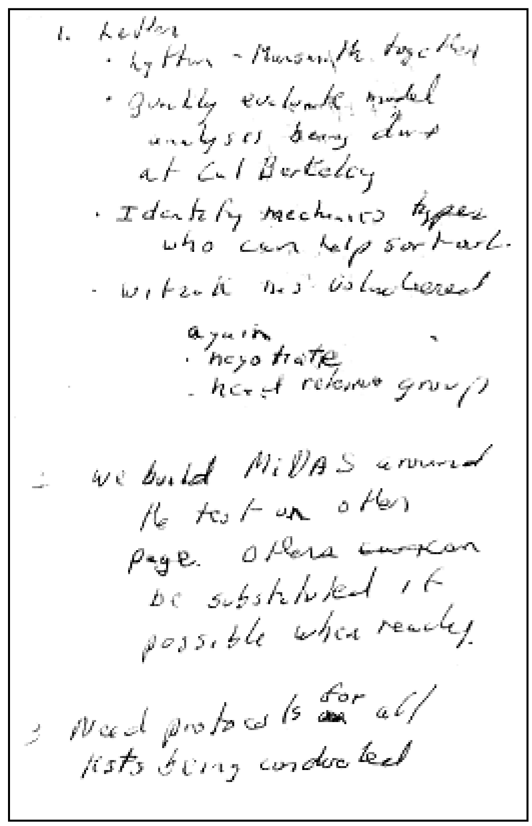
Hughes (Chuck Hughes A-006 team) will work
Harman (Tom Harman, FHWA) will do study on speed

2. Dynamic creep
   - Shear can be substituted if the bugs are worked out
   - Hire Rowe on A-001 to develop theory, etc for

Dissipated Energy Master Curve
   - Ed (Ed Harrigan, SHRP staff) has agreed

3. Run Dynamic creep Master Curve (fatigue)
   - Same as above
   - Continue work on bending beam if desired
4. Indirect Creep with fracture, cold temperature
5. Forced draft aging
   - Moisture?

Next page



Page 2

1. Letter
   - Lytton – Monismith together
   - Quickly evaluate model analysis being done at Berkeley
   - Identify mechanics types who can sort out
   - Witczak has volunteered
     - Again
       Negotiate
       Head review group
2. We build MiDAS around the tests on the other page. Others can be substituted if possible, when ready.
3. We need protocols for all tests being conducted.

FIGURE XX Notes Made by Tom Kennedy, Technical Leader Asphalt Research Program, July 25, 1991

Below are some comments on the points in the Kennedy note. The first page of notes is an outline of what the mix design system would be.

Laboratory Compaction

The first point (gyratory) deals with the laboratory compactory to be used. It was to be gyratory compaction with a 1° angle and 6 gyrations per minute. The A-003A team had been pressing for rolling wheel compaction to be used in the laboratory. NCHRP Project 9-5 that preceded SHRP had recommended gyratory compaction, and work was progressing on what the gyratory protocol should be. Texas four-inch gyratory compactors had been used in the NCHRP 9-5 project. The Corps of Engineers gyratory had also been discussed.

The Kennedy note indicates the gyratory compactor should operate similarly to the LCPC compactor (described in 4.5.3) except for the speed. The slow speed of rotation of the French gyratory had been identified as problematic, so studies were planned to determine a suitable speed. Tom Harman of FHWA was identified by Kennedy to do the work but it was later done at the Asphalt Institute by Huber.

Rutting Test

The next point on the Kennedy note, “dynamic creep” speaks to a rutting test. The A-003A team was recommending a repeated-shear-constant-height test to evaluate rutting, but there were still a lot of questions, and it was not clear if it would be possible to work them out. As a fallback, Tom Kennedy had decided that dynamic creep (repeated load axial deformation) could be used. This was a test that was being promoted by Ken Kandhal at the National Center for Asphalt Technology. Tom Kennedy was relatively confident that the repeated shear test could be sorted out and used. As the note says, “(repeated) shear can be substituted if the bugs are worked out”.

It was proposed to bring Geoff Rowe on to the A-001 team to evaluate the dynamic creep approach. Tom Kennedy had visited Professor Steve Brown at the University of Nottingham where Geoff Rowe was a graduate student at the time. Ed Harrigan, Program Manager for the Asphalt Research Program, had apparently already agreed.

Fatigue Test

The A-003A team argued that beam fatigue was the only valid way to measure fatigue properties. However, there were a host of issues that came with the test.

- The test had high variability.
- It required compaction of a slab and sawing to produce a specimen.
- There was an uncertain correlation between laboratory and field results.

The A-003A team members were focusing efforts to reduce variability and address ease of sample preparation and testing.

The Kennedy note indicates that dynamic creep master curves should be used for fatigue using Geoff Rowe to evaluate the test. Kennedy did not believe that issues with beam fatigue testing can be resolved but, as a consideration to the A-003A team, allows that beam fatigue can proceed.

Low-Temperature Cracking

The note indicates that indirect tensile creep with fracture will be used. There had been a debate whether the Thermal Stress-Restrained Tensile Test (TSRST) should be used. A cooperative experiment by Dr. Ted Vinson and Dr. Rey Roque had been done, and the A-001 team had already decided to proceed with the indirect tensile creep and tensile strength.

Laboratory Aging Protocol

Sufficient work had been done to decide that forced draft oven aging would be used.

Moisture Damage

Moisture damage was still up in the air. The net adsorption test had been developed by Dr. Christine Curtis of Auburn University. Work was continuing on the Environmental Conditioning System but the decision to use Tensile Strength Ratio would not be made until the fall of 1992. Hence the question mark about moisture damage on the note.

Kennedy Note, Page 2

The second page of notes speaks to things to be done to finalize the mix design system. The pressure of time is reflected in the comments. The SHRP Program is three years, ten months old. There remains only one year, eight months until the program ends. Decisions must be made if anything is going to be ready.

Kennedy is still hopeful that Monismith and Lytton can work together to jointly recommend a materials model and indicates that he will write a letter to that effect.

Still, Kennedy is uncertain if the A-005 material model that uses k1 to k5 is better, worse or the same as the C1 to C9 model proposed by A-003A. His need for an outside expert is evident, and he has talked to Dr. Matt Witczak of the University of Maryland about filling that role. Witczak was the main author of the “Brown Book”. He had the technical ability to evaluate the two approaches and was not already involved in the research projects.

Interestingly enough, this debate would continue for another year. The final decision regarding which tests and which models to use was made at a meeting at TRB headquarters on August 7, 1992. It was decided that the A-005 team was to use the set of tests developed by the A-003A team and extract information to determine the k1 to k5 used in their models.

Ensuring Development of Mixture Design System

The risk of failure was weighing heavily on Kennedy. The situation between Monismith and Lytton was becoming intractable and threatened to jeopardize the ability of the Asphalt Research Program to deliver a mixture analysis system. Therefore, Kennedy proposed the mix design system to be a modular system, whereby various components could be plugged or unplugged. Alternate tests, although not as rigorously developed as had been envisaged, were necessary in case no consensus could be reached in the A-003A / A005 debate.

4.6 PEOPLE AND ORGANIZATIONS

In addition to the program staff, committee members and researchers, there are a couple of other groups or people that deserve special mention. This section describes the spin-off Canadian Strategic Highway Research Program, C-SHRP, and those involved with that parallel effort. It also discusses the important role of graduate students and loaned staff in and after the research phase.

4.6.1 Canadian Strategic Highway Research Program

The Canadian Strategic Highway Research Program (C-SHRP) is an example of leveraging international research for local application. C-SHRP was operated by the Transportation Association of Canada (TAC).

TAC is similar to AASHTO as an association of highway agencies representing all the provinces in Canada. Unlike AASHTO, which controls the National Cooperative Highway Research Program (NCHRP), TAC had a less direct role in Canadian highway research. By circumstance, plans for SHRP were developing at the end of a Canadian Weights and Dimensions Study sponsored by TAC. Having just experienced the benefit of strong cooperation among the highway agencies, TAC members saw SHRP as another opportunity to achieve benefits through cooperation.

The keys to successful Canadian participation in SHRP include

- SHRP's invitation for international participation.
- Success of the weights and dimensions study.
- Ontario's willingness to under-write early participation in the SHRP planning process.
- Willingness of other provinces to be involved in a high profile project.

The Ontario Ministry of Transportation and Communications was the main conduit for Canadian participation in SHRP. In 1985 plans were developing for SHRP, and in September 1985 a workshop was held in Dallas, Texas, to gain input from the research community. Six research areas of study had already been delineated, and a team of technical experts had been appointed to develop a plan. A Canadian participant was included on each team as listed in Table 10.

During the same period, Ataur Bacchus of the Ontario Ministry of Transportation and Communications (OMTC) was loaned to TAC to write the original plan for C-SHRP. John Hill of TAC, who had just completed the Canadian Weights and Dimensions Study, was the manager of C-SHRP but left after the first few months. Greg Williams of Alberta Transportation filled in and then joined TAC to become the program manager.

The C-SHRP plan defined four roles of TAC within the SHRP effort.

- Monitor research and research plans in the U.S. SHRP Program. This led to inclusion of Canadian asphalt binders in the SHRP Materials Reference Library.
- Participate in the research activities. This was particularly evident in the complimentary research program for low-temperature cracking and test sections for Long-Term Pavement Performance (LTPP) studies. Canadian sites were included in the SPS5 LTPP Maintenance Treatment study (chip seals, crack sealing, slurry seals, etc.) and SPS-9A LTPP Superpave field site study.

- Technology transfer. As research results from the SHRP Program became available for implementation, the Canadian participants provided guidance for suitability and implementation in Canada. They also participated in evaluation and training activities during and following SHRP.
- Complimentary research. Additional research for Canadian conditions was identified. For example, the need for low-temperature cracking validation led to three controlled field experiments at Lamont, Alberta; Sherbrooke, Quebec; and Hearst, Ontario.

Table 10 Canadian Participants in SHRP Pre-Implementation Studies

Study Area	Name	Position and Affiliation
Over view and Integration	B.J. Hamm	Deputy Minister Nova Scotia Department of Transportation
Asphalt	Richard Langlois	Laboratoire Central Ministère de Transports Québec
Pavement Performance	Tom Christison	Senior Research Engineer Alberta Transportation Council
Maintenance	Lyle Smith	Assistant Deputy Minister New Brunswick Department of Transportation
Bridge Protection	Dave Marett	Chief Structural Engineer Municipality of Ottawa-Carleton
Cement and Concrete	Peter Smith	Director of Research and Development Ontario Ministry of Transportation and Communications
Snow and Ice Control	J.E. Gruspier	Research Engineer Ontario Ministry of Transportation and Communications

C-SHRP provided several loaned staff to SHRP headquarters in Washington, DC. As well as advancing the activities of SHRP, they helped fulfill the objectives of C-SHRP. Loaned staff included:

- Floyd Dukatch of Manitoba Highways and Transportation
- Guy Dore, Laval University
- Andy Horosko, Saskatchewan Highways and Transportation
- Ataur Bacchus, Ontario Ministry of Transportation and Communications
- Stella White, Saskatchewan Highways and Transportation
- Leonnie Kavanaugh, Manitoba Highways and Transportation

Towards the end of SHRP, Sarah Wells joined C-SHRP and worked with Greg Williams in Canadian implementation activities. Later, Steve Goodman joined Williams and Wells. TAC and C-SHRP took the position that benefits of Superpave asphalt technology would be sufficient for agencies to adopt the new technology. Unlike AASHTO, which maintains a set of test methods and standards used as the basis for state DOT specifications, TAC has no such role. Therefore, the mission of C-SHRP was one of demonstration and dissemination of information.

The Canadian Technical Asphalt Association (CTAA), which is a technical association holding annual meetings at various locations throughout Canada, became a key tool for dissemination of research results and coordination of implementation activities. C-SHRP worked with CTAA to form the Canadian User-Producer Group for Asphalt (CUPGA) in 1994, a parallel activity to formation of User-Producer Groups in the U.S.

CUPGA provided a sounding board for Superpave implementation and acted in a role similar to the AASHTO Lead States Program in the U.S. Presentations at CUPGA included implementation experiences of Canadian agencies and industry as well as updates on implementation activities in the U.S. In addition, C-SHRP displayed new Superpave equipment.

To facilitate experience with the new test equipment, C-SHRP purchased the binder equipment and the Ministère de Transport Québec (MTQ) set up a laboratory. MTQ provided testing to other provincial highway agencies as well as training on the equipment.

Today, Superpave binder specifications have been widely adopted in Eastern Canada and to a lesser extent in Western Canada. Superpave mix design is commonly used in New Brunswick and Ontario. Quebec uses an alternate form of mix design based on the Superpave gyratory compactor, but using elements of French mix design technology. Newfoundland, Prince Edward Island and Nova Scotia use aggregate specifications from the Superpave specification but continue to design using the Marshall hammer as the compactor. The move toward implementation of Superpave asphalt binder specifications and asphalt mixture design continues.

Generally, the participation of C-SHRP in the SHRP Program is viewed as a success. Improved cooperation among the provincial highway agencies in Canada is seen as a key benefit of the experience.

4.6.2 Graduate Students

All of the research efforts conducted at universities around the country relied heavily on graduate research assistants. The principal investigators were the driving forces leading the research, but the grad students were in the labs actually performing most of the hands-on work. Graduate students assisted with training efforts and technology transfer through papers and presentations during both the research and implementation phases. Many of the current leaders in the asphalt industry, especially in academic positions, were involved in the SHRP asphalt research and implementation.

Many of these graduate students are now professors with their own graduate students, continuing to work on refinements to Superpave and advances in asphalt technology in general. Some have left academia to enter industry as consultants or technical staff at paving associations, contractors, material suppliers, etc.

It may not be widely recognized how important the role of the graduate students was during and after the research phase. It is, perhaps, an unintended benefit that the SHRP research developed a strong core of researchers and educators who moved on to influence the industry and future generations of engineers.

4.6.3 Loaned Staff

Similar to the graduate students, the loaned staff members of SHRP developed expertise through their association with the program that they then took back to their home agencies.

While many SHRP loaned staff members worked in a variety of areas, a few focused on the asphalt research area or later became predominantly asphalt researchers.

The experience of working on an unprecedented research effort like SHRP could be very heady stuff. Loaned staff members were sometimes young, lower level employees, though some were also older and more established. For the young members in particular, working alongside internationally recognized researchers and engineers was educational and inspiring. When they returned to their agencies, they had more expertise than their colleagues and could champion the research products. They spread the word about SHRP through their organizations, states and regions.

Though the loaned staff was not large in numbers, it proved to be very successful and beneficial to the loaned staff members, their organizations and the SHRP Program as a whole. Loaned staff members came from state DOTs and internationally, spreading the word about SHRP far and wide.

4.7 REFLECTIONS ON THE RESEARCH PROCESS – HINDSIGHT IS 20-20

The following topics are but brief hints of coming attractions in the concluding chapter on "lessons learned."

Asphalt Program Success

It was anticipated (if not readily acknowledged) that the success of SHRP would be measured by the results of the asphalt program. By that metric alone, most would agree that SHRP was wildly successful – if for no other reason than the fact that the asphalt paving community (agency and industry personnel) "engaged" (and still do!) in a frequently boisterous, sometimes painful and disarmingly honest debate as to how this new technology could improve pavement performance. The Lead States Program, Superpave Centers, regionally-based User-Producer Groups and the *FOCUS* newsletter are but four examples of strategic engagement that were initiated during or shortly after SHRP and continue to foster the ongoing dialogue. Still, overselling any product can lead to frustration. Better to acknowledge some of the issues, imperfections, and shortcomings and note the plans for improvement. Consider Microsoft and Apple. We no longer use DOS despite the "bugs" in the numerous versions of the Windows operating system. Apple's iPhones are wildly popular despite the antenna issues with version 4.

Asphalt Program Scope, Objectives, Size and Complexity

The 1984 Blue Book made no mention of asphalt mixes. It was not until the Brown Book was published in May 1986 with proposed research contracts that asphalt mixes were mentioned, and then only briefly, as evidenced by the following:

> *"The asphalt research program will culminate in the preparation of performance-based specifications for asphalt and recommendations for an asphalt-aggregate mixture analysis system using modified or unmodified asphalts."*

Was this the classic private-sector nightmare of budget-busting, schedule-sabotaging scope creep? Today the Superpave mix design system imposes more stringent requirements on component materials (binder and aggregate) and volumetric properties of the composite, yet falls far short of the initial vision of a mixture analysis system. In part this is because of the initial obsession with binder chemistry and only superficial focus on asphalt-aggregate mixes. Admittedly, the problem of identifying and measuring key engineering properties of mixtures was much more difficult than had been anticipated, and the actual effort required to develop calibrated and validated performance prediction models—as evidenced by the $9 million expended by NCHRP between 1995 and 2004 to develop the Mechanistic-Empirical Pavement Design Guide—far exceeded the resources available to SHRP. Even today, in 2011, 18 years after the conclusion of SHRP, the paving community has just reached the threshold of implementing a system of specifying and measuring engineering properties for a pavement.

Asphalt Program Structure and Schedule

The Brown Book recognized that the "technical and administrative management of SHRP will be a complex endeavor requiring the most effective management and communication tools available" (*1*).

Although numerous institutional arrangements were considered in the Blue and Brown Books, SHRP was eventually administered as a new operating unit of the National Research Council. Like the Second World War Manhattan project, the asphalt program goal was clear, the direction less so; the schedule tight and the budget finite. Unlike the Manhattan project and the TRB/ AASHO Road Test, the researchers were not co-located and sequestered in Los Alamos, New Mexico, or Ottawa, Illinois, respectively. Furthermore, the researchers were not "hand-picked" but selected through a competitive process. Expert Task Groups (ETGs) were assembled to provide external technical review of each major contract.

Despite the SHRP mantra to "attract new blood," understandably, most of the key researchers were well established and highly regarded for their long-term efforts in particular areas of the asphalt arena. Because of the accelerated schedule, contracts with intersecting or overlapping goals had to be awarded in parallel rather than in series.

Did these factors alter the management team's ability to corral, both literally and figuratively, the researchers' ideas? Accommodate the personalities? Appease the egos? Establish esprit d'corps? Was it naïve to think that a renowned researcher would readily abandon his approach (upon which his career was built) in deference to his "competition?" Did the geographic hubs of asphalt research bear an eerie resemblance to the industry fragmentation referred to in the Blue Book? Though great technical expertise was assembled, were effective management skills more critical to success? Ability and willingness to coax and cajole the personalities and egos into a cohesive unit? Clear and concise communication? Transparent, timely and well-documented decision-making?

Despite the personal, practical, and logistical challenges associated with co-location of the research team, the anticipated benefits were numerous:

- daily and frequent interaction to reinforce the "team" goal, develop and nurture the team mentality (esprit d'corps), and foster cooperation rather than competition;
- clear statement of and recurring emphasis on the research goal: product-oriented, readily-implementable – perhaps a somewhat foreign concept to most academicians, for whom the common goal is *publication* of research results in a peer-reviewed journal;
- a sole focus which eliminates the competing interests of the academic environment (teaching, other research and "service" to the department/college/university/community); and

- regular reinforcement of the evolutionary nature of the research: only those ideas/concepts/products that furthered the goal would be pursued; all others would be jettisoned – another concept with which most academic researchers were unfamiliar.

The quarterly, pro bono reviews of voluminous technical reports by the ETGs, were, not surprisingly, uneven at best – superficial at worst. Rather than a large group (eight to ten) of unpaid "expert advisors," in future SHRP-type research endeavors, external, paid peer review should be considered because it might be more effective.

Asphalt Program Expertise

With few exceptions, namely chemists and statisticians, the key researchers were civil engineers. Given the keen focus on binder chemistry, the chemists played a prominent role; the statisticians a less visible but critical role, especially in terms of experimental design and data analysis. Despite the stated goal of "using the research results to develop standard tests" and the readily acknowledged importance of data management and implementation, the expertise needed to support these critical elements was assembled ad hoc or very "late in the game." The breadth of expertise needed might have included the following:

- mechanical and electrical engineers to assist with test equipment development;
- computer programmers for database structure, software development, and documentation; and
- marketers for implementation (early involvement with researchers and outreach to industry and stakeholders, political support and long-term, stable source of funding).

Obviously, provision of these staff would have required additional resources or diversion of resources away from the key objectives established for the program.

CHAPTER 5. IMPLEMENTATION PHASE

This chapter summarizes the efforts to implement the results and products developed during the research phase of the program. It describes the groups involved and their roles in the implementation process; the funding, organization and leadership of the implementation efforts; and the continued evolution of the products.

5.1 SEEDS OF IMPLEMENTATION DURING THE RESEARCH PHASE

With the research phase so short and intensely focused, it is safe to say that implementation of the research was not formally on the radar screen of the SHRP Executive Committee during the height of the research phase. That does not mean that it was not suggested that a plan for doing something with the research might be pursued, but it was certainly not on their continuing agenda. (Some instances where implementation was considered during the research phase were presented in Chapters 3 and 4.)

"In hindsight, we should have had the technical advisory committees report directly to the Executive Committee and be tasked with developing an implementation strategy," noted Frank Francois. This did not happen. In the third year of the program, some on the Committee suggested that implementation should be considered at some level. But it was probably not until the end of the program that the Executive Committee really started to focus on implementation.

A possible catalyst to focusing on implementation was the successful international scan on asphalt technology in Europe in September 1990. This scan showed that the U.S. had not cornered the market on high quality pavements and that there was a lot to learn from other countries. Stone Matrix Asphalt, performance-based laboratory testing equipment, contractor quality control, etc., were all key items that were identified for implementation. The scan team also reported that the U.S. could benefit from reexamining some of the ways research and implementation were conducted. They noted that the results of research in Europe are "aggressively" marketed and that research and marketing go hand-in-hand, helping to ensure that successful research results are implemented quickly and effectively (*15*).

This scan led to a stronger focus on implementation of the SHRP results. The scan team included representatives from NAPA and the DOTs who were strong advocates for change. Many ideas surfaced at the time and impacted how SHRP outputs would be addressed for the first time. Ideas generated included a catalog of products, regional asphalt User-Producer Groups, equipment procurements and the like. Much credit for the implementation focus goes to former Indiana DOT Chief Engineer Donald W. Lucas, who was on the Executive Committee.

Also in 1990, the SHRP mid-course assessment meeting was held in Denver, allowing a large number of agency and industry personnel to meet with the SHRP researchers to review the progress to date and offer suggestions for the remainder of the entire research program. (The roster of attendees is in Appendix B.) This meeting marked the first major public discussion of implementation. In the opening plenary session, AASHTO President Kermit Justice observed that the involvement of the AASHTO member states would "intensify as SHRP moves into its second half." He also urged the attendees to start using what they learned about at the meeting. "Research results do not put themselves in use automatically," he said (*3*).

SHRP Chairman John Tabb also encouraged attendees to start thinking about implementation. He said, “We are counting on you to start the implementation effort here and now by going back home to champion the emerging products of SHRP within your own agencies.” He also recognized that implementation is a major effort, requiring “money, effort, time and patience.” He likened SHRP implementation to the advent of personal computing. “SHRP implementation … will require highway agencies to budget for new capital expenditures for equipment. We’ll have to expect a few problems at first as we work out the bugs. Some people will refuse to adopt the new ways of doing things. Some will resist change, but if we give them enough support, they will come around,” Tabb said (*3*). This statement certainly proved to be insightful as Superpave implementation progressed.

At the same meeting, Dean Carlson announced the creation of a new position within FHWA’s Office of Technology Applications (OTA). Dick McComb, who had been FHWA’s first staff member on loan to SHRP, was named Special Assistant for SHRP Implementation. It is interesting to note that this position was created within OTA, not Research and Development, signifying that the products were deemed to be ready for implementation.

As implementation assumed a greater prominence, the SHRP team developed several implementation documents, but it is safe to say that none captured the full imagination of the country. There was little grasp of how comprehensive and far-reaching the asphalt implementation efforts might be. In fact it was not until 1993 that the full thrust of the asphalt specification and the asphalt mix design system was defined and recognized by the broader highway community.

As the research program was developed and refined, it changed gradually from a liquid asphalt research program to a mix design and analysis program as well. This change dramatically influenced how the results might be applied nationwide. The scope of work would require fundamental changes in more than just liquid asphalt formulations. The new scope of work would literally touch every DOT, hot-mix plant and inspector in the nation. At the mid-course assessment meeting, it was recognized that the adoption of the system – whatever shape it finally took – would require major expenditures by agencies and industry for capital equipment, training, changes in operations and material supplies, and more (*3*).

In addition to the suggestion that these impacts should be quantified soon to help organizations prepare to implement Superpave, other implementation comments were also made at the mid-course assessment meeting (*3*). These included:

- Circulating the proposed mixture test methods, including the compaction method, for review.
- The issuance of draft specifications (“straw man” specifications) during the research phase was seen as a good tool to involve a wide range of people in the process and help them prepare for eventual implementation.
- The concept of using User-Producer Groups and other industry task groups was supported as a short-term implementation strategy.

The need for an early and comprehensive training program was also identified by those participating in the Asphalt -Aggregate Mix Specification Workshop during the mid-course assessment meeting.

5.2 TRANSITION TO IMPLEMENTATION

Although the seeds of implementation had been sown earlier during the research phase, implementation planning activities increased markedly as the research phase drew to a close. During 1992, the groundwork was laid for the later implementation efforts in the SHRP offices and at FHWA. Implementation efforts began in earnest in about 1993.

5.2.1 Transition to Implementation at SHRP Program Office

While many believe that there was little in the way of formal implementation at SHRP during the research phase, there was considerable discussion of what research would be used by the state DOTs and how they would use it. It was not until 1992, however, that the framework of an Implementation Plan was developed by the SHRP Program Office. It outlined eight main steps for implementation over a seven year time period, from 1993 through 2000, as shown in Figure 37. Additional details of other activities to support the main steps are shown in Table 11.

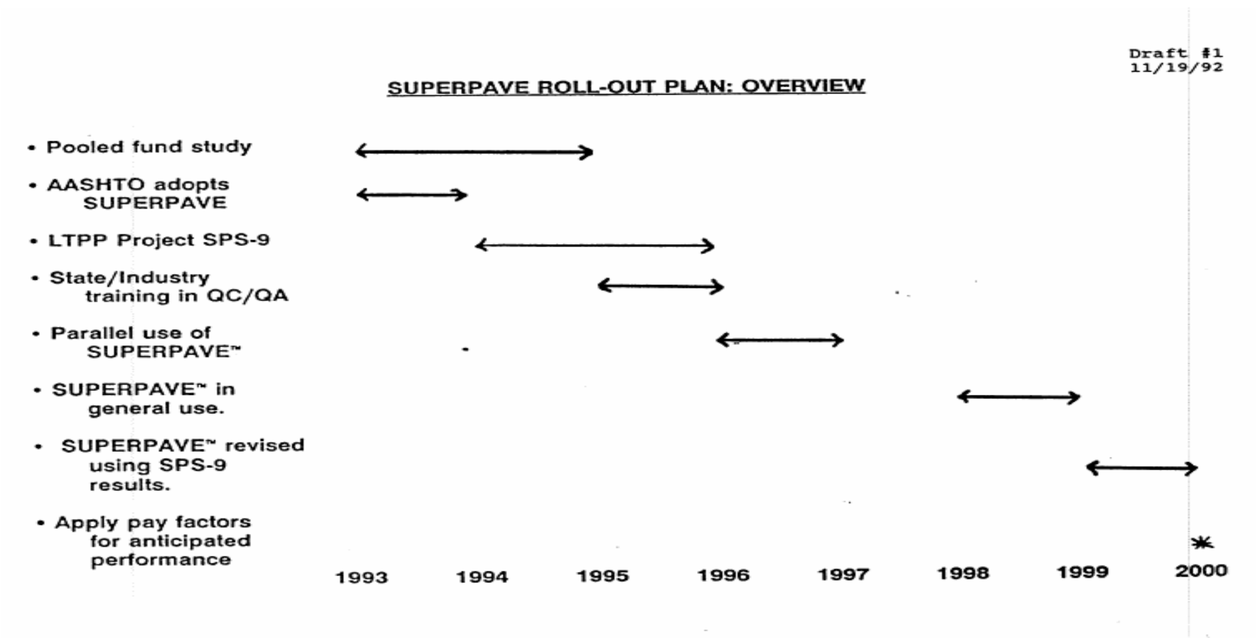


Figure 37 Overview and Main Steps of Superpave Roll-Out Plan (circa 1992)

Table 11 Detailed Steps in the SHRP Program Office Implementation Plan (After Kulash, 1992)

Year(s)	Planned Implementation Activity
1993 - 1995	Pooled-Fund Study and Development of Precision/Bias Statements
1993	National Training Center in Operation
1995	University Professors Trained
1993 - 1994	AASHTO Adopts Superpave Standards
1993 - 1995	Development of Field Control Procedures (NCHRP 9-7)
1994 – 1996	LTPP SPS-9 – Field Proof Testing
1994 – 1998	Refinement of Superpave Performance Prediction Models
1994-1996	Superpave taught in standard university curriculum
1995	Establishment of Regional Training Courses with NHI
1995	Incorporation of Superpave QC/QA into joint paving handbook
1995-1996	State / Industry Training
1996 – 1998	LTPP Integration of Mix and Structural Design
1996 - 1997	Parallel Use of Superpave by States
1998 – 1999	Superpave in general use in most states
1998 – 2000	Superpave revised to incorporate SPS-9 results
2000	Application of Pay Factors based upon performance results

This timeline was presented to the SHRP/TRB Committee by Gale Page on behalf of the SHRP Asphalt Advisory Committee in October 1992 and was sent to key individuals involved in Superpave implementation in November 1992 by Damian Kulash. The presentation provided the Asphalt Advisory Committee's view of implementation as well as that of a state DOT ("AASHTO user agency"). The goal of the presentation was to look ahead at what would be needed to work together, move forward with a positive attitude, and raise the level of technicians. Implementation was seen as an "upfront and continuous focus" from the beginning of the program. There were seventeen items identified as early concerns regarding the specifications and tests, including the following:

1. AASHTO Approval
2. Definitive
3. Simple
4. Timely results
5. Reduced variability
6. Familiarity with test/training
7. Account for multiple effects
8. Equipment acquisition
9. Better end-product/ validation
10. Need for people/space/money
11. Allow for regionalization
12. Adaptable to QC/QA
13. Impact on local materials
14. Justification for resources
15. Priority with CAO/Commitment
16. Plan for implementation
17. Contractor/ Material supplier involvement

Ultimately, this boiled down to three major concerns about SHRP implementation:

1. The gap between management and materials
2. Concern about the level of validation
3. The need for a mechanism to carry on product development

Finding the resources to continue the development of products and foster implementation was a major issue at this time. The needs for refinement, more research, validation of the binder and mixture products, and integration of the system with QA and field testing were recognized. FHWA was seen as the "primary working vehicle" for implementation with AASHTO, industry and the regional user/producer groups as partners.

The immediate implementation needs included the resources to continue the efforts, a structure for ongoing coordination of efforts and support for that structure. Implementation was seen as a complicated process with several stages, illustrated by the "Valley of Implementation" (Figure 38).

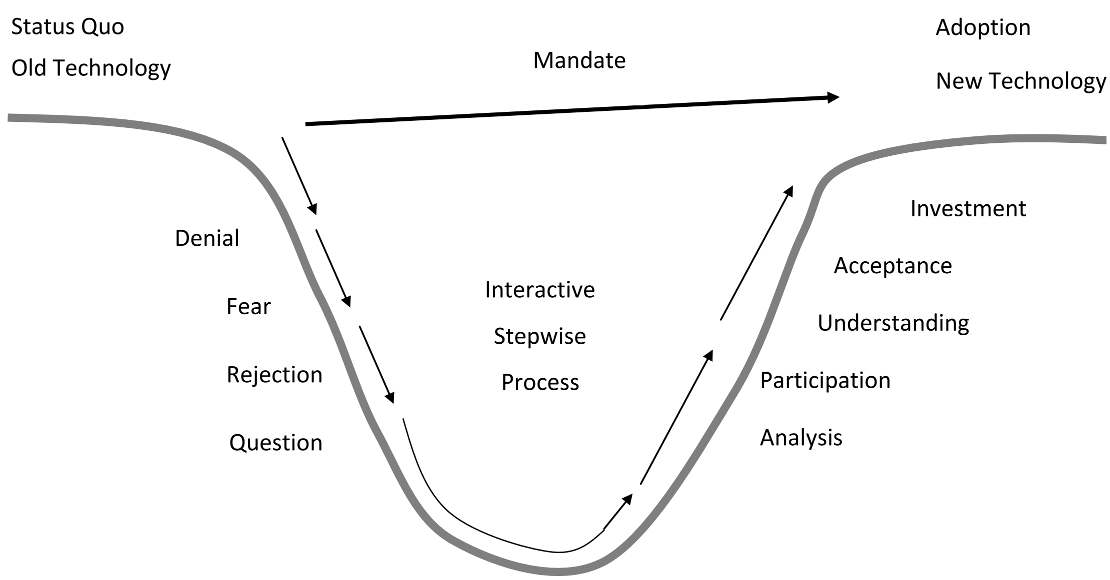


Figure 38 The Valley of Implementation

5.2.2 *Transition to Implementation at FHWA*

While it is well-documented that FHWA did not play a lead role during the research phase, it was assumed that FHWA would be playing a role in the implementation of the research. Heretofore, the only major roles played by FHWA were Executive Director Dean Carlson sitting on the Executive Committee and FHWA Loaned Staffers Dick McComb and Paul Teng. The implementation efforts at FHWA began in 1992 and were expected to continue through the rest of the 1990s (*16*).

Several barriers to the formal participation of FHWA existed at the time. The first was the lack of staff understanding, in any specific detail, of what was in the research program, how complete the work was, and what the full impact of the work would be. The second was the question of which FHWA organization would take the lead – the Office of Technology Applications (OTA) or the Asphalt Division at the Turner-Fairbank Highway Research Center (TFHRC).

To address the first concern, FHWA staff members Ted Ferragut and John D'Angelo paid a visit to Damian Kulash and introduced themselves. Kulash presented his understanding of the implementation effort, which appeared to be a very aggressive top down approach that might take upwards of three years or so. He thought it a good idea for FHWA engineers to begin the process of understanding and learning what was in the program.

This led to John D'Angelo focusing on understanding the binder issues. He visited Dave Anderson, which in turn led to a Denver meeting with other asphalt binder experts including Joe Goodrich, Gayle King, Mark Bouldin and Ray Pavlovich. They were meeting to look at Anderson's work with master curves on each binder. The binder experts redirected D'Angelo to understand the individual test procedures, equipment and results. D'Angelo later expressed that he felt uncomfortable at the meeting, as if the presence of FHWA staff was perceived as meddling.

The beginning of an answer to the second concern occurred in 1990, when Dick McComb was assigned Special Assistant for SHRP Implementation. The significance of this decision was that the responsibility for this effort was placed in the Office of Technology Applications, not the Office of Research. The thought at the time was that the research was completed and that implementation meant a program to apply the technology, not to evaluate it. This meant to all concerned that the work in Superpave and all the other areas was ready to use. Putting McComb in the OTA office clearly emphasized this assessment.

The plan also included an aggressive plan for the continued refinement of the Superpave system and its adoption by the states and industry. In short, the plan called for the system to be finalized by 2000 and fully implemented by 2005.

5.2.2.1 1992-93 Implementation – FHWA Timeline

One key element of managing the program was the establishment of a formal timeline to achieve acceptance of the binder and mix specifications and tests as standard practice. FHWA developed a timeline, shown in Figure 39, to guide implementation efforts. The timeline aimed to make the binder specifications the national practice by 1997 and the mix by 2000, by the majority of states.

However, there was a more subtle reason for the timeline; senior managers associated with the Superpave research phase really had very little comprehension as to how long the road to adoption would really be. The FHWA timeline was an attempt to bring that point home. The timeline, for example, outlined the procurement time, prototype and first article testing, manufacturing time, and, of course, time to develop a basic understanding of the binder specification. That alone was a three year process. A similar process existed for the mix equipment and for training at the National Asphalt Training Center as well.

This FHWA plan was developed as a result of a meeting between Ted Ferragut, Damian Kulash and John Bukowski (of FHWA). Ferragut and Bukowski showed Kulash the constraints of getting things accomplished at FHWA and around the country. They explained the time it took to buy equipment, to staff trailers, to set up training courses through NHI, etc. It was a good discussion and led to a realization of how long implementation would take and what items of work were necessary to accomplish all the goals. Neither group, however, really had a feel for the journey in the various states and the dynamics taking place within both the asphalt and hot-mix industries.

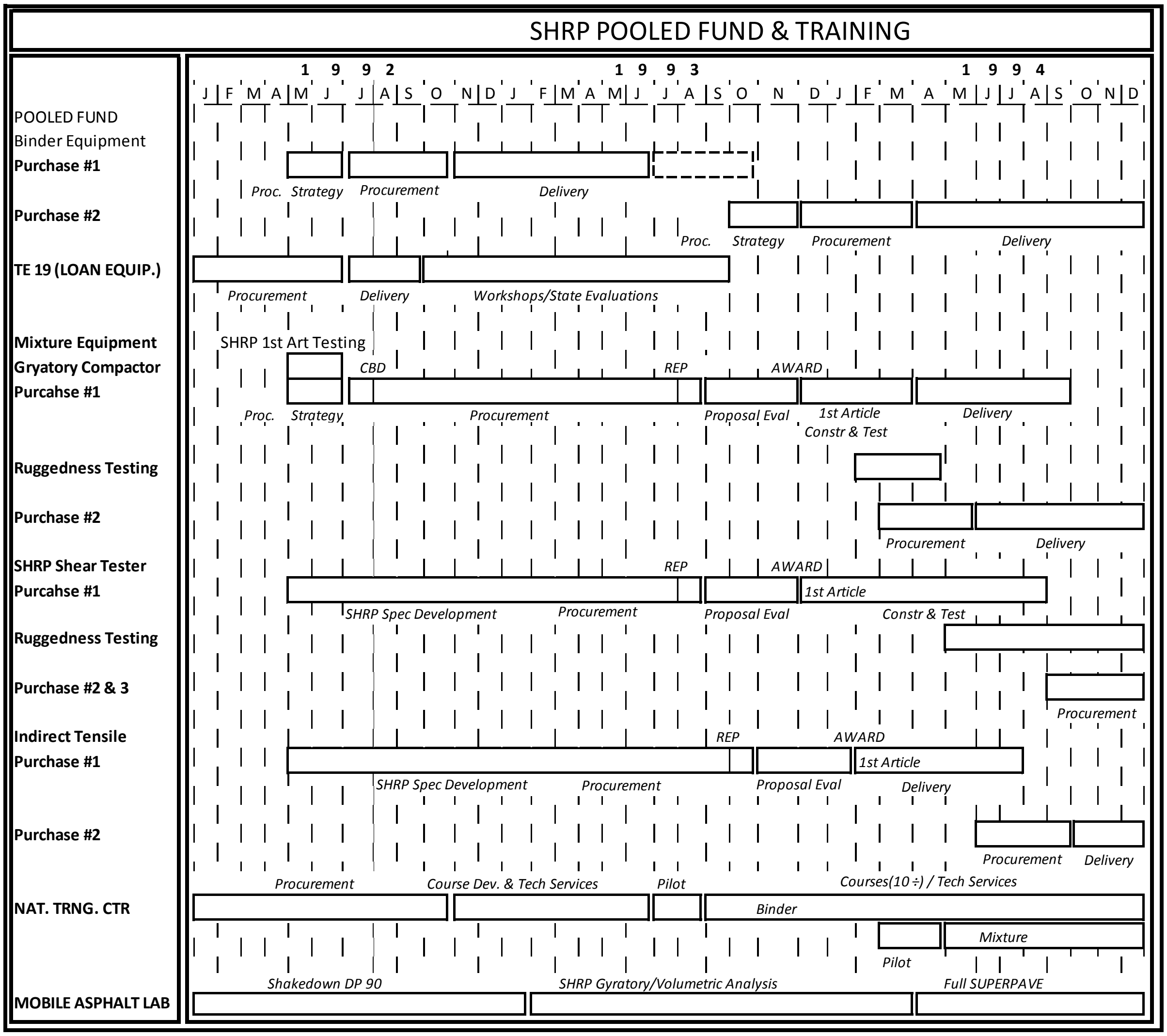


Figure 39 FHWA April 1992 Timeline for Superpave Implementation

The implementation plan for Superpave that was eventually developed called for the following activities and organizations:

- Pooled-Fund Equipment Purchase
- TE19 Technical Assistance Program
- National Asphalt Training Center (NATC)
- DP90 Mobile Asphalt Lab Program

In addition to these activities, other groups and efforts also played a role, as will be discussed in Section 5.4.

5.2.2.2 Pooled-Fund Equipment Buy Program (1992-93)

One of the first major efforts of the FHWA Implementation Program was the acceptance of a pooled-fund study that would procure sets of binder and mix equipment for each state DOT. If there was a kick-off to implementation, this was probably the key activity. However, there was considerable work and effort behind this effort.

The pooled-fund study was originally announced at the TRB Annual Meeting in January 1992. This was followed by a March 1992 meeting in Alexandria, Virginia. One representative from each state was invited to this meeting to discuss the equipment, how it was used, why it was needed, and how it could be procured for those states that wanted to participate. The idea behind the timing of the meeting was to begin rolling out the equipment before the end of the research phase to kick start implementation.

This effort received considerable scrutiny. Real concern was voiced about FHWA's aggressive role in organizing and managing this meeting. However, there were significant accolades as well about something finally happening.

"This was a significant undertaking," noted Haleem Tahir, then with the Maryland State Highway Administration. "It meant that we were serious in undertaking implementation. Having equipment in the hands of the materials engineers was the key to breaking down the barrier from theoretical to practical."

Each state had the option of receiving one set of binder equipment (bending beam, dynamic shear rheometer, the PAV, the direct tension tester, the rotational viscometer), a gyratory compactor, and the SST and IDT performance testers if they so desired. They also had a choice to select the first, second or third buy in the program. The total price for the equipment was $325,000 for a full set of equipment; the binder equipment was estimated to cost $98,000, the mix equipment $227,000 and $10,000 for training. All but one state eventually took advantage of the opportunity to buy the binder equipment (except the direct tension tester) and gyratory through the pooled fund, prior to 1996.

The trailer with the binder equipment was on display at the March 1992 meeting, along with the resilient modulus equipment, the Rainhart Texas gyratory and the prototype Superpave gyratory. Also displayed were the Marshall hammer and the rotating base Marshall hammer.

The SST and IDT were not initially ready for DOT use and were integrated with the Superpave Centers Program. Because of their complexity and expense, it was deemed appropriate to evaluate them on a smaller scale before outfitting every state with the devices. (The SST was estimated to cost $300,000 and the IDT $150,000 in 1997.)

Critical to the success of the equipment buy was the strong desire by FHWA engineers to award dual contracts for each piece of equipment. "We did not want to be stuck with one supplier nationally; we were looking into the future," noted John Bukowski, FHWA asphalt pavement engineer. "It took some real convincing of FHWA procurement to accomplish that. Coincidently, they had hired a procurement officer from the Department of Defense who was invaluable in getting the multiple awards through the procurement process."

SHRP did not release equipment procurement specifications as part of the research phase. It took considerable time working with the researchers, equipment manufacturers, and key DOT engineers to develop these specifications. "We had to stay away from method specifications and brand names and describe the performance of the equipment. We concentrated on that aspect for all the equipment. We used a two-step concept in the buy, looking for the first article to pass rigorous testing followed by the manufacture and shipment of the approved equipment," remembered D'Angelo.

5.2.2.3 Superpave Loaner Equipment (1992)

Under TE 19, the Superpave Technical Assistance Program, FHWA bought five sets of Superpave equipment to lend to the User-Producer Groups to help make the industry more familiar with the new equipment and procedures. This was a key step prior to the pooled-fund equipment buy. Several of the regions moved them around in trailers (University of Utah, Penn State University, and National Center for Asphalt Technology); others set them up in one place (Arizona DOT, Indiana DOT).

Dave Anderson was also hired to conduct binder workshops with this equipment. Anderson and others, including his graduate students, provided assistance with setting up the equipment, provided training, advised on data analysis and performed other activities. FHWA support staff also provided technical support and training in state labs and trained visiting engineers and technicians from private labs in the binder lab at Turner-Fairbank. By 1996, FHWA support staff had visited at least sixteen states to provide hands-on training and support.

5.2.2.4 National Asphalt Training Center (1993)

The implementation effort called for the development and initiation of the National Asphalt Training Center (NATC). The Asphalt Institute was awarded that contract in September 1992. A second, five-year contract was awarded to the Institute in September 1995 for NATC II. It called for hands-on training for the first wave of DOT engineers and lab technicians. The concept was to train the technician or engineer in a formal setting, promote dialogue, and break down the anti-change atmosphere that surrounded Superpave implementation. Training slots for one binder technician and one mix technician were allotted to each DOT, with priority given to DOTs buying equipment on the first and second buys of the program.

The first course taught was a binder training course in July 1993. Demand for training was high; by the fall of 1996, 18 binder and 18 mix courses had been taught, training over 700 engineers and technicians from agencies, industry, FHWA and universities. Pilot one and two-week courses on the mix analysis system were also developed and presented under NATC II. The Institute continued to offer the binder and mix training after the second contract expired (on a fee basis).

Additional activities performed by the Asphalt Institute are described in 5.4.7.

5.2.2.5 The Trailer Program (1991)

FHWA had been working with an asphalt trailer from 1986 on under Demonstration Project 90, looking at volumetric controls for hot mix. The concept was to use Marshall volumetrics during construction. This work gave the FHWA staff exceptional experience in understanding hot-mix production variability, including the connection between mix design and quality control. Eventually, this work was recognized by the Association of Asphalt Paving Technologists in 1991 with the W.J. Emmons Award for the best paper. This work was important for several reasons, since it showed that:

1) the FHWA could transition to Superpave or AAMAS, and
2) the FHWA could work with the new equipment and provide hands-on expertise to the states.

FHWA quietly began the procurement of two additional trailers, anticipating the demand for Superpave evaluation and training. Two trailers would be dedicated to mix design testing and evaluation projects. The third trailer would be dedicated solely to binder equipment testing, including ruggedness and precision/bias testing. The trailers were intended to support the SPS-9 studies and also developed mix designs and assisted in construction quality control (QC) testing at WesTrack. [1996 FHWA Implementation Status Report] A key element of the trailer program was providing hands-on demonstrations of the test equipment to aid implementation efforts in the states.

The work at the trailers was performed in two ways. Current mixes used by the states were tested according to the SHRP protocols and compared to the Superpave standards. In addition, true Superpave mixes were designed and analyzed using the available materials. The trailers also included a training component. A one to two-day workshop was offered at each site the trailers visited.

5.3 FOCUSED IMPLEMENTATION BEGINS: THE ISTEA YEARS

In 1993, the SHRP research was concluded and the implementation phase began in earnest. The SHRP Program Office had made some efforts at implementation during the research phase, but in essence, the research curtain had fallen and the implementation curtain was raised in 1993. Efforts initiated in 1992 continued while many new efforts were undertaken.

While the research phase ended in 1993, the SHRP office on Connecticut Avenue remained open until June 28, 1994. The last year was spent, by an ever-dwindling staff, publishing reports, closing contracts and other close-out activities. Planning for implementation was one of those close-out tasks.

The status of Superpave at the time was later summarized by Tom Harman from FHWA (*17*). The products at the end of the research phase consisted of research grade prototypes of equipment without biddable specifications and few to no manufacturers; test methods that were not yet AASHTO standards; limited test sections (fewer than 1000 tons of mix had been placed); and a small circle of people knowledgeable about the technology. Estimates of the number of knowledgeable people were that there were no more than 30 engineers and scientists, no more than ten executives and no more than two contractors who were truly in the know.

5.3.1 Funding and Managing the Implementation Phase

Congress had allocated funds to FHWA for implementation of the SHRP results in the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA). Surprisingly, the funding was provided with no strings attached, meaning FHWA and its implementation partners could use the funds as they saw fit. This opened the door to some new, innovative and aggressive implementation approaches. The key to the entire implementation program was this line item for SHRP implementation at the level of $50M, in addition to FHWA's normal technology development funds. (An additional $58 million was provided in the same legislation for the continuation of the LTPP program.)

The path by which this implementation funding came about at this critical time is not very clear or well-documented. It is also unclear how FHWA eventually got the lead implementation responsibility. All paths appear to have gone through Tom Larson. Larson had moved from the Pennsylvania Department of Transportation to FHWA as the Administrator. He believed that FHWA was well positioned to do technology implementation since it had research and technology application arms in Washington and field offices throughout the country.

Immediately, many questions began to surface:

- Should FHWA actually lead this State-designed and State-managed research program? If so, who at FHWA was in charge?
- Would there be a committee structure?
- What were the first two or three activities?
- What about the research? Was it really finished?
- What was the long-term goal?
- Where do we get the needed equipment?
- What are the test protocols?
- How do we train people?
- Who really knows that this works?
- What does implementation really mean?

After many draft plans were considered, detailed implementation plans were developed for SHRP as a whole (*18*) and for the Asphalt products in particular (*19*).

The overall purpose of SHRP implementation was to apply those research findings that would improve the quality, efficiency, safety, performance, and productivity of our nation's highway system. For the first time, implementation was defined. The overall plan stated (*18*):

> *Assuming that implementation means "bringing into practice" or "carrying out the means to bring into practice", there are essentially three levels of first-stage implementation that will be carried out in this program. The three levels are necessary since the SHRP products generally fall into one of the following categories:*
>
> 1) *those that are essentially complete, available for widespread use, and can be deployed with minimal training or field/laboratory evaluation.*
> 2) *those that will require local State/industry field and laboratory test and evaluation along with significant training prior to general acceptance and use.*
> 3) *those that are incomplete without continuation of the research and/or must be integrated with other ongoing research prior to use.*

Grouping implementation this way established an important departure from SHRP advertising and outreach efforts. Heretofore, the country was led to believe, rightly or wrongly, that all SHRP products were ready for implementation and adoption. This was reinforced with the issuance of the SHRP Product Catalog with nearly 150 products described as ready-to-go. In point of fact, however, all those products were not ready for widespread implementation; this was certainly true of the asphalt products.

In this plan, the goals of the implementation process were defined as well (*18*):

- To fully and professionally communicate final SHRP research findings to the US highway community.
- To immediately bring into voluntary practice those SHRP products and techniques that are essentially complete and are implementable with minimal training and/or evaluation.
- To promote field and laboratory testing of those SHRP products that require use of local materials and adaptation to regional, State or specific industry practices.
- To advance those promising but only partially completed SHRP products/processes through further research, development, test and evaluation, standard setting, and institutional awareness.
- To provide early exposure and training on the use of SHRP products and initiate activities that will enhance long-range educational efforts.
- To develop and implement both short and long-range marketing strategies for SHRP products by taking full advantage of existing industry delivery systems.
- To promote activities by standard setting organizations – AASHTO, the American Concrete Institute (ACI), ASTM, etc. – that enhance the acceptability and credibility of the SHRP products.

The Plan also looked at what might happen to implementation should elements outside the control of FHWA come into play. Successful implementation identified the following dependencies (*18*):

- Top executive awareness, understanding, and support of the program - State, Federal, and industry - and continued promotion of the highway program and progressive and technology centered.
- Full and continuous Congressional financial support.
- Effective use of State apportioned Federal-Aid highway research funds to test and evaluate SHRP products.
- Continued voluntary State and industry participation on technical working groups and Expert Task Groups.
- Proper integration of research scope and findings from various programs and organizations - FHWA, National Cooperative Highway Research Program (NCHRP), Corps of Engineers (COE), Federal Aviation Administration (FAA), private sector, etc.
-

5.3.1.1 1993 Organizational Direction - FHWA

As noted earlier, Dick McComb had been appointed the Special Assistant for SHRP Implementation in 1990 and had been assigned to OTA. This implied that the research was complete and products were ready for implementation. Since 1990, however, awareness had grown that there was a need for additional research and development efforts before the research results would be ready for implementation. This awareness led to the establishment of a three tiered management structure. The Office of Technology Applications remained the lead office directing the implementation efforts.

SHRP Implementation Coordination Group (SICG). The mission of the SICG was to oversee the implementation efforts by the Federal participants and to ensure that that State, industry, and academia are kept informed of implementation efforts and issues. This internal FHWA group coordinated activities as appropriate with other interested groups, including the TRB-SHRP committee. It included just about every major office manager in FHWA but worked behind the scenes and was not very visible to others.

Technical Working Groups. Membership in the TWG's included a cross section of FHWA, State Highway Agency, academia, and industry representation. The Asphalt TWG was appointed to deal with technical issues related to Superpave implementation. The general responsibilities of the TWG's included the following:

- Receiving and identifying SHRP products.
- Assessing and evaluating the technical nature of SHRP products.
- Identifying potential technology development, implementation and marketing strategies.
- Recommending the establishment of specific Expert Task Groups under the Technical Working Groups.
- Reviewing the work of Expert Task Groups that are addressing details of specific technologies.
- Coordinating with and involving additional technical partners, technology users and producers, as required.
- Identifying resource needs.
- Executing implementation programs aggressively and professionally.

Expert Task Groups. Expert Task Groups (ETGs) were named to address specific topics for the various SHRP research areas. In the case of Superpave, there were three ETGs: binder, mix, and performance modeling. The composition of the ETG's included a cross section of FHWA, State Highway Agency, academia, and industry representation. The roles of these ETG's were to provide technical oversight of various technical efforts.

The Office of Technology Applications addressed several key functions for FHWA. They included:

- Tracking and controlling the financial affairs.
- Publishing and distributing newsletters, promotional documents, publications and exhibits.
- Developing and maintaining a product database

One key part of the plan, however, was to assure that all of SHRP implementation was done with coordination, cooperation, and collaboration with the program offices. This led OTA to work very closely with the Offices of Program Development, specifically the Pavements, Construction and Maintenance, and the Structures Divisions, to allow them to take on a more prominent role in the program and to provide technical staff to execute the specific projects.

This was easier said than done and caused considerable internal friction at first. OTA had a rather wide latitude to work with DOTs and industry while keeping the field offices informed. The Operating Offices were used to issuing policy, guidance, and regulations – more command and control functions.

One final element of the program was to establish regional SHRP implementation technical coordinators. In response to a July 1992 memo from Executive Director Carlson, the nine FHWA regions and the Federal Lands Offices assigned personnel to coordinate activities within a certain technical area. While a significant element of the assignment was to coordinate the flow of information, the need for more technical involvement was paramount in order to make the transfer timely and effective.

In hindsight, the Superpave program taxed the OTA staff for the first three years of the program. "We had to understand the technology and train ourselves, develop and implement procurement contracts for equipment, give technical assistance to the DOTs and industry, participate in non-stop conferences and workshops, and prepare articles and news releases," noted John D'Angelo. "We also had to train and work with the entire FHWA organization to assist in this culture change that was underway. It was very difficult. If we had to do it over again, we would have trained our FHWA people first and set up more, stronger regional technical assistance programs for the DOTs."

Ferragut noted that this was one of the goals with setting up the Superpave Centers. "I did not think at OTA we could ever work with 50 DOTs, the FHWA, and the industry. Nearly all the work was coming through three engineers and a manager at FHWA Headquarters. No one really wanted to hear about the challenges, only when Superpave was going to be adopted."

5.3.2 Implementation in Full Swing

Under ISTEA, then, the Superpave implementation efforts really took off. FHWA had a significant amount of funding and had started many implementation efforts to further develop and refine Superpave and move it into routine practice. Soon the situation was going to change radically with the passage of the Transportation Equity Act for the 21st Century (TEA-21).

Before discussing TEA-21 and its impact on Superpave implementation, the next section will discuss some of the other groups and activities that were initiated, often with FHWA support, during the first part of the implementation phase.

5.4 KEY GROUPS AND ACTIVITIES FOR IMPLEMENTATION

Under FHWA during the first phase of implementation, several groups became active in the Superpave implementation efforts – some were spins offs of existing organizations and others were new entities developed specifically to participate in Superpave implementation. Most of these groups and activities are still in existence though they have adapted to changes in the status of implementation. This section describes these groups, their organization, funding and activities. These groups include the Superpave Centers, AASHTO, the Lead State Team, the User-Producer Groups, the Expert Task Groups, TRB and the Asphalt Institute.

Some activities were focused around Washington (at FHWA, TRB and AASHTO) and others took place across the country on a regional or local level. The common thread between all of these groups was FHWA, which was working to coordinate activities across the country.

5.4.1 AASHTO

As pointed out earlier, the SHRP Research Program was funded by a take-down from the states' Federal-Aid funding. The SHRP products were intended to be implemented by the states. Clearly, then, the states needed to be heavily involved in implementation efforts. The main vehicle for involving the states was AASHTO.

5.4.1.1 SHRP Research Implementation Coordinator

One of the steps AASHTO took to facilitate implementation of the SHRP products was to hire Haleem Tahir as SHRP Research Implementation Coordinator, using funds provided by FHWA, to coordinate and provide support to the various contributors to SHRP research implementation, particularly the Subcommittee on Materials. The FHWA and the Lead States Team relied extensively on Tahir through the process. Tahir connected the AASHTO Subcommittee on Materials (SOM) with FHWA and the Lead State Team, as well as the FHWA TWG and ETGs. He held the position for over ten years, shepherding the provisional standards through to full standards and keeping the community informed of implementation progress.

Tahir had been with the Maryland State Highway Administration, so had a deep appreciation of issues the states would face as implementation proceeded. He also had familiarity with the SHRP Research Program and with his former colleagues from other states, whom he would continue working with in his new role.

5.4.1.2 Provisional Standards

Recognizing that the SHRP Program would create an unprecedented need for the rapid development of new standards, AASHTO, through Tahir's leadership, created a new class of standards, known as provisional standards. These were intended as "dynamic" standards for immediate use by the states, with the understanding they would be revised or updated more frequently than mature standards. This change has been credited with being extremely important for the eventual implementation of Superpave. Provisional standards got the methods out there for people to use while still making it clear that refinements would be likely. Past experience has shown that rolling a product out before it is really ready for implementation and then finding problems can be the death knell for the product. Those early users get a bad taste in their mouths and may not be willing to try a second time.

Ron Sines, then with the New York State DOT, was deeply involved in revisions to the provisional standards. Following a Lead State Team meeting in Baltimore in 1997, Sines began assembling information to guide the somewhat extensive revisions. Members of the Lead State Team met after the Mix ETG meeting in Orlando in March 1998 and reviewed the proposed changes. The revisions included increasing the density at $N_{initial}$ from 89.0% to 91.5% for lower volume roads to allow the use of finer mixes and lower fine aggregate angularities. Another major change was the simplification of the aggregate property tables. Since many of the people who voted on the AASHTO ballots had little to no experience with Superpave, Sines wrote white papers explaining why changes were needed and how the proposed changes would address the problems. These were instrumental in getting the changes approved through AASHTO.

5.4.1.3 Task Force on SHRP Implementation

The Task Force on SHRP Implementation was created by AASHTO in 1991 to develop plans to further the implementation of the SHRP research products. The task force collaborated with a number of other entities, including the SHRP Program Office in its early years and FHWA, TRB, the AASHTO states and the private sector throughout its life. The task force sunset in 2000, with its mission largely accomplished.

The task force was chaired by B. F. Templeton from the Texas DOT. Templeton was succeeded by John Conrad from Washington State in about 1998. See Table 12 for the members of the task force.

This task force would prove instrumental in securing funding to support implementation efforts when TEA-21 severely limited FHWA’s funding. In addition, the task force created the Lead State Team concept described in 5.4.3. Other key recommendations from the task force included supporting the establishment of the pooled-fund equipment purchase, the creation of the SHRP Research Implementation Coordinator position at AASHTO, and a number of resolutions passed by AASHTO committees.

The task force’s major initiative was the Lead States Team. The task force was also involved in supporting the Superpave Centers, the LTPP program and the SHRP assessment project. (The Superpave Centers are discussed in detail in 5.4.2.) The task force supported the LTPP program by encouraging states to construct test sections and planned to oversee implementation of products from LTPP as they became available.

Table 12 Members of AASHTO Task Force on SHRP Implementation

Member	Representing
Joe Mickes (1996-97)	Missouri DOT
Bob Templeton (1996-97)	Texas DOT
Ken Shiatte* (1996-97)	New York State DOT
Joe Deneault (1996-2000)	West Virginia DOT
John Conrad (1996-2000)	Washington State DOT
Haleem Tahir (1996-99)	AASHTO Staff
Amy Steiner (19960	AASHTO Staff
Dwight Bower (1997-98)	Idaho DOT
Don Lucas* (1997-2000)	Indiana DOT
Linda Thelke (1997-99)	Wisconsin DOT
Eugene E. Ofstead (1997)	Minnesota DOT
Larry R. Goode (1997-98)	North Carolina DOT
Gary L. Hoffman (1997-2000)	Pennsylvania DOT
Gary Carver (1998-99)	Wyoming DOT
David Ekern (1998-2000)	Minnesota DOT
A. R. Giancola (1998-99)	National Assn of County Engineers
Douglas Rose* (1998-2000)	Maryland DOT
Don Goins (1999-2000)	North Carolina DOT
Jim Ross (1999-2000)	Idaho DOT
Mike Halladay	FHWA

*Primarily working with Superpave Lead State Team.

The SHRP assessment project was a communication effort to share the “practical successes of implementing SHRP technology” through a series of flyers called *Road Savers*. One of the most significant Road Savers issues was the 1998 report “Assessing the Results of the Strategic Highway Research Program.” This benefit-cost study of SHRP (not just Superpave) was conducted in 1996-97 by the University of Nevada – Reno (UNR). Through case studies, the report showed that Superpave projects were “holding up well to heavy traffic and extremes of climate.” They predicted that adopting the binder specifications alone could increase service life of an overlay by 25% (from 8 to 10 years) and that if all agencies adopted the performance grade specification within five years, the increase in service life, based on a nationwide average, could save $637 million per year. Fewer maintenance related delays (user costs) and less vehicle maintenance could save motorists $1.7 billion per year over 20 years if the binder specifications were implemented within five years. This report was the first to put hard dollars to the benefits of implementing Superpave (*20*).

5.4.1.4 SCOH, SOM and SCOR

The AASHTO Standing Committee on Highways (SCOH) is the parent committee that oversees the activities of its subcommittees. The representatives are usually the chief engineers or other technical members of the state DOTs. It is a highly influential group responsible for the development of policies, standards and guidelines. Resolutions approved by SCOH carry much weight, as they reflect the backing of the high ranking members of the state DOTs.

Subcommittees under SCOH include Design, Construction, Materials, the Technology Implementation Group (TIG) and more. (The TIG is essentially modeled after the SHRP Product Implementation Task Force and is charged with championing research products that are ready for implementation.)

SCOH authored or endorsed several crucial resolutions in support of Superpave or various implementation strategies. These resolutions included a 1997 resolution urging all states to implement the Superpave products uniformly (*21*); this resolution was ultimately unsuccessful but was a valiant effort. SCOH also passed a resolution in 1997 in support of the Superpave Centers that encouraged states to participate in and help fund the Centers' activities (*22*). The resolution had been initiated by the AASHTO Task Force on SHRP Implementation. That Task Force also formulated a 1998 resolution supporting SHRP implementation activities and the LTPP program that help to fill the funding gap created by TEA-21, which was supported by SCOH (*23*).

The Subcommittee on Materials (SOM) has the authority to publish and keep current specifications for materials used in the construction and maintenance of all transportation facilities, and specifications for standard methods of sampling and testing such materials. Therefore the SOM assumed the responsibility for publishing and updating all the Superpave-related standards, including the important provisional standards.

The Standing Committee on Research (SCOR) is focused on ensuring that high quality research is conducted to meet the needs of the state departments of transportation. SCOR also looks ahead to implementation of the research findings. SCOR has been essential in securing the needed follow-up research—on the order of $20 million between 1993 and 2005—that helped to enhance, refine, and close gaps in Superpave.

5.4.2 Lead States Team (1996-2000)

In 1996, a new entity emerged in the implementation arena. The AASHTO Task Force on SHRP Implementation had been discussing the status of implementation across the country. As is typical with implementation of most new technologies, particularly in the highway industry, some states were much further along with implementation than others. The task force surmised that the learning curve for other states could be shortened if those states with more experience would share their practical, real-world expertise. Thus, the idea of the AASHTO Lead States was born. While the actual source is hard to trace, credit for the concept probably goes to a host of people including Bill Burnett and B. F. (Bob) Templeton of TxDOT; Joe Toole and Byron Lord of FHWA; Joe Mickes, Missouri DOT; Don Lucas, Indiana DOT; Haleem Tahir of AASHTO and others.

"I think the concept of Lead States probably popped up in the midst of some negativity about SHRP," recalled Bob Templeton. "Quite a few DOTs were floundering; lots of negativity had surfaced. Superpave was part of the negativity. It was recognized, however, that a few states were doing just fine with Superpave. From that kernel came the idea that maybe those that were [successful] with the technology could help those that were struggling."

The task force felt a cooperative effort to adopt new technology would be a benefit. They cited the following advantages (*24*):

- Economic benefits from sharing resources,
- Reduced duplication of efforts,
- Teamwork,
- Reduced burden on any one state,

- Faster implementation, giving states the benefit of earlier cost savings, and
- Better understanding of the technology and end results.

In June 1996, Task Force Chairman Templeton wrote to six states inviting them to assume the role of Lead States for Superpave implementation. The six selected Superpave states – Florida, Indiana, Maryland, New York, Texas and Utah – accepted and agreed to share their experiences, both good and bad, with other states to promote more rapid implementation of the technology.

As a Lead State, the participating agencies expressed their commitment to implementing the technology and helping other states do the same. The concept of a Lead State was that those states would share their "proficiency and knowledge … with others in order to advise new users of potential benefits and shorten their learning period" (*25*). Lead States were expected to:

- with other states using a variety of means.

In August 1996, Templeton wrote again to the six Superpave Lead States asking them to identify their representatives, champion(s) and industry representatives to be included as members of the team. (The resulting Superpave Lead State Team membership is shown in Table 13.) The involvement of industry in the process was seen as a critical element, since individual contractors or material suppliers typically did not share their expertise readily with other contractors, who are their competitors (*25*).

The first meeting of the Lead State team was held September 18-19, 1996, in St. Louis, Missouri. At that meeting, the members of the team developed a mission statement and action plan. They also identified key milestones, available resources, challenges and communication between the members.

The Superpave Lead State Team developed the following mission statement (*24*):

The Lead State will assist in the uniform implementation of the Superpave system (Superior Performing Asphalt Pavements) by documenting and sharing experiences, furthering development and providing guidance related to the practical application of the technology.

The individual goals and strategies they planned to achieve the mission are detailed in Table 13.

Table 13 Members of the Lead State Team for Superpave (*24*)

Member	State	Representing
Paul Mack, Team Leader	New York	DOT
Kenneth W. Shiate (later D. Rose, MD, and J. Deneault, WV	New York	AASHTO Task Force Liaison
Gary Owens	New York	FHWA
Jim Musselman	Florida	DOT
Larry Smith	Florida	DOT
Gale Page (1999)	Florida	DOT
Cynthia Lorenzo (1996)	Florida	DOT (Public Information)

Jim Warren	Florida	Industry
Rick Smutzer (later David Andrewski)	Indiana	DOT
Gerald Huber	Indiana	Industry
Rebecca McDaniel	Indiana	Superpave Center
Lee Gallivan	Indiana	FHWA, IN Division
Larry Michael	Maryland	DOT
Jim Dunne	Maryland	FHWA, Region 3
Jitesh Parikh	Maryland	FHWA
Maghsoud Tahmoressi	Texas	DOT
Erv Dukatz	Texas	Industry
Gary White	Texas	FHWA, TX Division
Wade Betenson	Utah	AASHTO SCOH Liaison
Cameron Peterson	Utah	DOT
Gerald Barrett	Utah	DOT
Mike Worischeck	Utah	Industry
Tim O'Connell	Utah	Industry
Tom Harman	FHWA HQ	Technical Resource
Gary Henderson	FHWA HQ	Superpave Delivery Team
Jeanne Fuchs	Missouri	Facilitator
Martin Delaney (1999)	Nova Scotia	Transportation and Public Works

Table 14 Superpave Lead State Team Goals and Strategies

Goal	Strategies
1. Develop local state pool of technically experienced people to assist with pilot projects in design, construction, and trouble shooting by January 1997	a. Identify key people in each Lead State: i. Key contact and technical experts ii. List association, position and area of expertise iii. Action steps 1) Collect names 2) Publish and distribute b. Resources: Use FHWA to compile and make initial distribution. Suggested routes to distribute names: i. User-Producer newsletters ii. FOCUS publication iii. Roads and Bridges, Better Road, etc. iv. AASHTO Journal v. World Wide web (www)
2. Provide channel of communication for Superpave users and implementation partners	a. Utilize internet as a clearing house for Superpave issues b. Utilize print media to provide current Lead State activities and update on Superpave issues
3. Set up data collection system by June 1997	a. Quarterly surveys b. Develop procedure to capture information from Goal 1 c. Develop a "system" for disseminating results of collected data and information d. Develop procedure to capture info from other sources
4. Get each state and agency to develop a realistic plan for Superpave implementation by October 1997	a. Provide "template" of typical implementation plan (ex. New York State) b. Work through User-Producer Groups (UPGs) c. Identify management level person to champion Superpave (agencies) i. Get management commitment ii. Set up communications between technical level positions iii. Offer assistance of Lead State iv. Encourage participation in U-P G d. Encourage partnering between users and producers at program and project levels
5. Identify training needs and available resources	a. Provide list of potential training needs for Superpave implementation b. Provide list of available resources for meeting Superpave implementation training needs
6. Ensure Superpave Regional Centers actively support Superpave implementation	a. Manage data collection system b. Coordinate with regional Superpave Centers on technical activities, construction, training and trouble shooting c. Representation on Regional Superpave Centers' Steering Committee by Lead States d. Promote Regional Superpave Centers to provide referee PG

	Binder testing services.

The Lead State Team continued meeting in St. Louis annually through September 2000. (See Table 15.) At the meetings, the team reported on activities during the year, reviewed and refined goals, brainstormed new goals, and more.

Table 15 Lead State Team Workshops

Year	Conference/Workshop Title
1996	Lead States Take the Lead in SHRP Technology Implementation
1997	Leading the Technology into the 21st Century
1998	Leading the Technology into the 21st Century: Sustaining the Momentum
1999	Leading the Technology into the 21st Century: Preparing for the Future
2000	Sunset to Sunrise

The Lead States Team worked very closely with the AASHTO Subcommittee on Materials (SOM). The Lead States' plans for implementing the Superpave system included a strong linkage to the appropriate Technical Sections.

The Superpave Lead States Team also worked as a go-between for follow-up NCHRP Superpave research projects and the AASHTO SOM. They recommended significant advancements to four mix standards based on this research, as well as their own guidelines. SOM adopted the recommended improvements, publishing them in the May 1999 interim edition of the AASHTO Provisional Standards.

One interesting issue the Lead State Team had to deal with was the lack of access of DOT personnel had to the internet (and industry was typically even further behind). In 1997, for example, the task force noted that use of internet to communicate between team members "has more than doubled in a year" but that there were still some DOTs without internet access. This seems hard to believe today, when most people carry internet access with them everywhere through their cell phone.

The facilitator, Jeanne Fuchs, was provided for the Lead State Team meetings by the Missouri DOT and was invaluable in keeping the team focused on the task at hand. Since all the meetings were held in St. Louis, the facilitator was able to continue to work with the team through the duration of the program, establishing a strong rapport.

The following are among the activities that the Superpave Lead State Team accomplished (*26*):

- Completed a survey in February 1997 to assess the level of training that would likely be required in the areas of binder testing, mix design, and QA. A total of 39 states responded to the survey and indicated that over 1,000 people would need binder training and nearly 4,000 people would need mix design and QA training. Training needs for FHWA, executive staff and management, field personnel and others were also identified.
- Produced a marketing video entitled *Superpave … Tomorrow's Pavements Today* to promote Superpave to upper level staff in agencies and industry. (This was produced by the New York State DOT and the FHWA Division Office.)
- Provided guidance to the AASHTO Subcommittee on Materials concerning recommended changes to the Superpave specifications in 1997.

- Recommended high-priority research topics to FHWA and the Mixture Expert Task Group including reevaluating N_{design}, investigating the need for different VMA values for fine and coarse aggregates, and addressing field construction concerns.
- Established a Lead State website for dissemination of information.
- Developed guidance statements (on N_{design}, fine aggregate angularity, coarse aggregate angularity, reclaimed asphalt pavement, field construction concerns and the use of modified binders) that could be applied within the Superpave system to encourage uniform implementation. This guidance was distributed to all states.
- Completed influential annual implementation surveys in 1997 through 2000, charting the progress of implementation nationwide. These surveys were distributed to all members of SCOH, SOM, the Lead States, FHWA, the User-Producer Groups, Superpave Centers and industry. They served as the basis for countless presentations and publications. This benchmarking effort did much to encourage states to adopt the system and to convince various industry partners of the national commitment to its adoption.
- Published a list of experts willing to be contacted to provide a variety of technical advice through the *FOCUS* magazine and other publications (Superpave center websites, trade publications and others).
- Developed an example implementation plan to illustrate the issues states should address in their own plans. This guide was also distributed to all the states. Champions to lead Superpave implementation were identified in some twenty states by mid-1997.
- Defined the "unchangeable core" of Superpave that must be maintained to implement a uniform plan. Recognized that some elements of the original Superpave system would be changed at a state or regional level, but attempted to identify those elements that could not be changed without irreparable damage to the overall system.
- Provided a list of Superpave training resources and providers to the LTAP Centers and via the internet.
- Issued 1998 Lead State guidance on the practical application of Superpave. This report was distributed to all states in 1998 and was reported on in *FOCUS*, *FHWA Superpave Update*, the *Asphalt Contractor* and via the internet.
- Established liaisons from the Lead State Team with all the Superpave Centers.
- Encouraged the passing of a resolution by the AASHTO SOM and Subcommittee on Construction urging uniform implementation of the Superpave system.
- Sponsored a number of conferences and workshops on Superpave implementation in conjunction with the FHWA.

5.4.2.1 Lead State Guidance

The Lead States periodically released guidance, formally and informally, to assist states and industry. One of the main documents was released in June 1998 following a March meeting in Orlando with FHWA and a number of states. The group met to discuss a variety of technical issues. The discussions suggested that there were steps states could take to ensure successful implementation, which were then outlined in the document. The Lead States were still striving to achieve uniform adoption of the Superpave system, so the recommendations in the guidance document were also referred to AASHTO as proposed revisions to the standards.

The 1998 guidance dealt with the following issues (*27*):

- Determination of the appropriate N_{design} level for a project.
- Use of a 20 year design life for estimating traffic regardless of the actual expected service life of the pavement.
- Lowering the N_{design} level by one increment for mixtures located more than 100 mm below the pavement surface.
- Using previous state specifications for aggregate properties if those standards are more stringent than the Superpave standards.
- Adopting the Superpave Mixture Expert Task Group's recommendations for using reclaimed asphalt pavement in Superpave mixes.
- Increasing the upper end of the allowable dust to binder ratio for coarse-graded Superpave mixes.
- Using the aggregate bulk specific gravity to calculate VMA or accounting for the use of the aggregate effective specific gravity by either increasing the VMA criteria or determining a correction factor to adjust the VMA.
- Clarifying that short-term oven aging should not be applied to plant-produced mixtures, since they have already been aged during production.
- Changing the $N_{initial}$ criteria for low-volume roads.
- Widening the acceptable range of VMA values (through modification of the voids filled with asphalt (VFA) criteria) for 9.5 mm mixes.
- Issuing guidance regarding the use of Stone Matrix Asphalt (SMA) mixes under the Superpave system.

5.4.2.2 Superpave National Implementation Surveys

One of the most frequently cited accomplishments of the Superpave Lead State Team was the collection and dissemination of nationwide implementation information through annual surveys. The first of these was completed in May 1997 to document the status of implementation through 1996. As an indication of the level of interest, 48 of 50 states, plus the District of Columbus and Puerto Rico responded to the survey. While the amount of Superpave mix placed varied by state, the overall average amounted to only 1% of total projects and 2% of total HMA tonnage nationwide. A total of 47 states had implementation plans by 1996, but only 19 of these were in writing.

Figure 40 summarizes the results of the annual surveys and demonstrates the generally rapid growth of the technology through the increase in the number projects. By the year 2000, when the Lead States Team sunset, the survey showed that performance-graded binders had been fully implemented by 48 states (including DC); one additional state and Puerto Rico had plans for implementing the binder specifications. The last survey also showed that Superpave mixture specifications had been fully implemented by 25 states and 15 additional states had implementation plans in place.

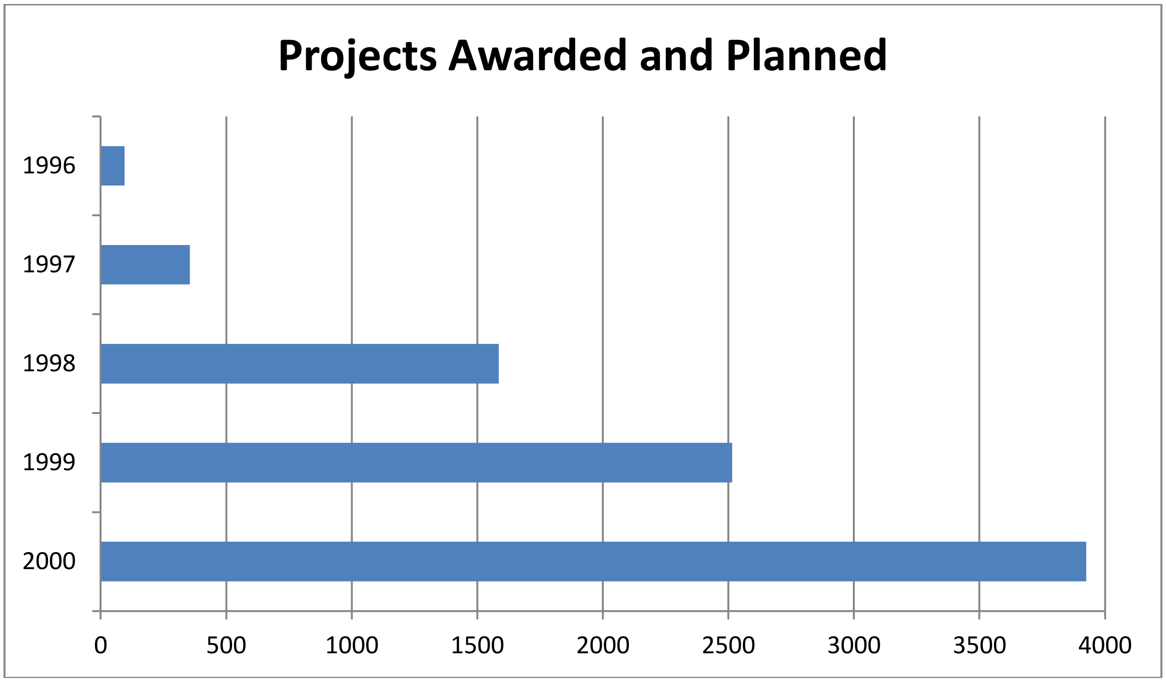


Figure 40 Superpave Projects Awarded and Planned (in 2000) (*28*)

In each survey, respondents were asked to identify what they perceived to be the barriers to implementation. From the beginning, industry acceptance, state budget restrictions and facility limitations were cited as primary barriers. Institutional issues were less frequently cited. Other potential barriers included limited knowledge about and experience with the system, as well as training for agency and industry personnel. Facility limitations declined steadily from 1997 on, presumably as states implemented their plans and obtained the needed equipment. Other implementation issues that were noted in 1999-2000 included lack of validation, high turnover of experienced personnel, QA implementation, and others. Training and lack of knowledge continued to be issues for some states, but were not as frequently cited as in previous years.

5.4.2.3 Transition Plan

The Lead State teams were programmed to "sunset" in 2000. A fixed duration was set for the groups to provide time for their work to be accomplished without establishing a continual entity. The thinking was that at some point in the not-too-distant future, the work of the teams would be complete and the implementation would be fully mature, though there might still be some remaining issues.

Accordingly, the Lead States developed a transition plan to describe those steps necessary to continue to advance Superpave technology in the absence of the Lead State Team. Although Superpave implementation had grown dramatically, in 2000 it was still not fully accomplished and there were remaining research needs. The team recognized the following elements that it deemed critical to the further development of Superpave technology (*26*):

- Leadership

- Expert advice
- Expert user support
- Long-range plan for research
- Standards adoption
- Visibility
- Communication
- Coordination
- State-of-the-art implementation
- Technology transfer and training
- Universal implementation

Recommendations were made in each of the areas above for what needed to be done and what organization should assume responsibility for ensuring completion. The details are probably not important here, but the fact that plans were made to continue the effort is. In implementing a substantial program, the work to move the advancements into routine practice can take significantly longer than the research itself. Unless plans are made – and followed – to continue the efforts over a long period of time, the eventual implementation is in jeopardy. While not all of the Lead State Team's recommendations were followed to the letter, the issues were documented so that they could not be overlooked.

Part of the development of the transition plan also included developing white papers describing the perceived future role of various groups, including the Superpave Centers and universities, in future implementation efforts. These white papers helped to lay the groundwork for the final transition plan and helped to show how existing groups could play an increasing role in the refinement and dissemination of the technology. (Some of the recommendations are addressed elsewhere in this report.)

5.4.2.4 Bottom Line

So, were the Lead States effective and beneficial? The overall consensus seems to be yes. They did focus attention on Superpave and some of the issues with implementing it. Not all states/industry took advantage of the opportunities offered by the Lead States. Some felt they were not having problems and were leaders in their own right. Perhaps others were not aware of what the Lead States could do for them despite the attempts at publicizing the program. However, many states did make use of the resources provided by the Lead States. AASHTO and the Expert Task Groups listened to what the Lead States Team had to say and incorporated many of their recommendations into specifications and activities. The implementation surveys were widely distributed and referenced. Anecdotally, it was reported that non-technical agency administrators would sometimes see the surveys and question why their state was not implementing Superpave as rapidly as other states. Information from the Lead States Team was incorporated into many other groups' communications (such as the Superpave Center newsletters, training materials, *FOCUS*, and other articles, etc.).

5.4.3 Superpave Centers

One might think that the concept of Superpave Centers was driven in large part by the idea of implementing FHWA's organizational ideas of regional and local management of SHRP and Superpave efforts. That was in the background, but one of the keys was the troublesome process of procuring SSTs and IDTs.

"They were expensive, bulky, and required excessive training and knowledge in fundamental asphalt properties," noted Ted Ferragut. "We had no manufacturers, no specifications, no test standards, and, really, no idea on tolerances for any of the equipment."

The concept as implemented was for FHWA to select manufacturers that could produce a limited number of SST and IDT devices, then deliver and install one at each Center. Ruggedness testing would be performed on the operation and output data of all the SST and IDT units. Under this phase, each of the Centers receiving delivery of the SST and IDT would conduct tests on a group of similar asphalt mixture specimens. The similarity of produced data on each SST and IDT was to be examined, the data produced imported into the Superpave software system and the similarity of output results examined. A team of experts, provided by the FHWA through the equipment manufacturer, would monitor the testing sequences, review the appropriateness of the data output of individual tests, aid each participant in the collection of data and incorporation of the data into the Superpave software, and analyze the results.

After this initial evaluation phase, a more detailed equipment and procedural precision and bias analysis would be performed jointly with the Centers and the TFHRC. Finally, as needed, the Centers would be utilized to assist states in initial SPS-9 design.

The FHWA team discussed this concept with the various committees, pointing out that was much more prudent to evaluate the devices first rather than to buy them for the DOTs. The idea was to establish a pyramid of acceptance: from one laboratory during the research phase to five laboratories during the evaluation phase. The risk of having a general buy of this equipment then finding it was not working as envisioned, plus the time it would have taken for a major buy, convinced all concerned that the one-to-five concept was prudent.

This left the team with having to develop the regional concept and identify laboratories willing and able to set up programs to both evaluate this equipment and to become training grounds for DOTs and industry, going beyond the National Asphalt Training Center.

It should also be mentioned that a catalyst behind the concept was Administrator Larson's desire to promote Centers of Excellence around the country, including one at Penn State for Superpave. These ideas were eventually coupled into the Superpave Center concept.

5.4.3.1 Superpave Center Selection and Roles

The first step was to divide the country into five regions, identify at least one good laboratory or university in each, and identify a champion who would make the Center concept work. In some regions the selection of a center location was fairly obvious and in others there was more competition. The Centers eventually selected included the Pennsylvania State University, Auburn University, Purdue University, the University of Texas at Austin and the University of Nevada at Reno. It was also agreed to help the University of California at Berkeley (UCB) to upgrade the equipment they used during the research phase, but not to call it a Center. (UCB did partner with the Center at Reno and worked with the other Centers as well.)

The rationale behind selection of these particular centers in 1995 included:

1) PennDOT. Penn State was selected at the suggestion of Administrator Larson and with Dr. Dave Anderson still at the University. This Center was to serve the northeast states and work with the Northeast Asphalt User-Producer Group.
2) Indiana DOT. Purdue University was selected with Don Lucas, INDOT, in mind. He had championed the Superpave concept and was willing to make it happen at Purdue. This Center was to work with the North Central Asphalt User-Producer Group.
3) Auburn University was tied to the National Center for Asphalt Technology, under the guidance of NAPA. Their involvement was intended to give the industry a voice. This Center served the southeast U.S. and worked with the Southeast Asphalt User-Producer Group.
4) The University of Texas was selected with Tom Kennedy in mind as well as Bob McGennis. Kennedy managed the research team that developed Superpave and McGennis had substantial early Superpave experience. Principal funding of this Center was provided by the Texas DOT and for the period from 1995 to 1998, this Center played a significant role in the implementation of Superpave. This Center was to serve the southwestern states and Rocky Mountain User-Producer Groups.
5) University of Nevada – Reno was chosen with Jon Epps in mind. It was intended to serve the Pacific Coast and Rocky Mountain States User-Producer Groups. University policies made it difficult for Epps and his team to participate in outreach activities such as teaching NHI courses. In addition, the West Coast states were generally not very enthusiastic about Superpave, so they did not call on UNR for much assistance. All these factors contributed to a difficult road for the Western Superpave Center to fully materialize as a regional Center.

Ultimately, the overall mission of the Superpave Centers was to assist the states and industry in each region with Superpave implementation. The common goals included providing technical leadership on Superpave, evaluating the Superpave equipment and test protocols, assisting with testing materials, and providing training. The specific goals of each Center included other tasks or different emphases to best serve their regions. Flexibility was built into the Center concept to allow the Centers to best serve the needs of their regions.

FHWA provided test equipment and start-up funding for each Center beginning in 1995. The long-term plan for the Centers was for them to become self-supporting. FHWA would pay for specific project work, but each Center was expected to come up with operating and administrative plans and funds. Three of the Centers – in the Northeast, Southeast, and North Central regions – were funded through pooled-fund arrangements. The other Centers were never able to formulate a business plan with buy-in from the surrounding states. The Texas DOT generously funded the Center in Austin and encouraged the participation of the surrounding states. The high level of TxDOT funding, however, seemed to "brand" the Southeastern Superpave Center as a "Texas Center." So although the Center staff provided training and other services to the surrounding states, those states did not feel compelled to join in as strong financial partners. The Western Superpave Center in Nevada struggled in part because of the initial reluctance of the states in the West to fully embrace Superpave. Administrative hassles with the university also hampered some of their activities. In short, the Centers that involved the surrounding states fully from the beginning were generally more successful in the long run. This is not to say the other Centers were not successful – they all were in their own ways – but the Centers that had strong regional support also had greater longevity and visibility.

Each Center developed its own strengths in response to the needs of its region. The Southeast Superpave Center, for example, developed a strong regional research program where two or three high-priority projects of regional interest were completed each year. The Northeast Center of Excellence for Pavement Technology, as the Northeastern Center is named, was (and remains) heavily involved in training and certification for PennDOT and developed a binder technician certification program. The North Central Superpave Center was (and is) active in training, technology transfer and research on state, regional and national levels. The Western Center was active in national research, particularly at WesTrack. The South Central Superpave Center was heavily involved in training and technical services, including evaluating new models of Superpave Gyratory Compactors, conducting Superpave mix designs for various state DOTs, and managing evaluations of Superpave mix test equipment.

Even among the Centers that established pooled-fund arrangements, however, there were differences in how the funds were allocated. The Southeast Center, for example, essentially set up individual state accounts and a price list; states could choose what tasks to fund. The North Central Center, on the other hand, put all the state funds together to fund certain general activities considered essential for the long-term operation of the Center (so-called base funding).

While each Center was eventually operated differently, there were commonalities. All were involved, in one way or another, with training. All the Centers also had an advisory group consisting of representatives of the various states and, usually, industry. Each Center was also involved in ruggedness testing, research and communication.

Training was a major activity for the Superpave Centers in the early years. Eventually thousands of people received training from the Centers. Courses ranged from two-hour management overviews of Superpave through half-day sessions on the gyratory compactor to intensive, week to two-week long, hands-on binder testing and mix design courses. Participants in the courses included agency and industry personnel. While most of the agency personnel were from state highway agencies, other agencies were represented as well, including cities and counties, the FHWA, the Federal Aviation Administration and others. Industry trainees included hot-mix contractors, material suppliers, equipment manufacturers, consultants, industry association staff and others. All of the Centers (except for the Western Center) taught the National Highway Institute Superpave courses.

Initially, the Centers coordinated their activities quite extensively. Meetings among the Center staffs occurred roughly every six months at one of the Centers (including the University of California at Berkeley). (Figure 41 shows the primary representatives of the five Superpave Centers at a meeting at the Asphalt Institute in about 1996.) Through these meetings, the Centers developed a rapport and shared their growing pains. Since these labs were among the very first to use some of the new, complicated equipment, there were numerous equipment and testing issues to resolve. These meetings also gave staff members a chance to see how each Center was set up, share experiences with the equipment and test protocols, and make plans for future collaborative work. Representatives from the Asphalt Institute (NATC) and FHWA also participated in these meetings. Occasionally others, such as the equipment manufacturers, attended as well.

The Centers worked together in 1998 to develop a joint proposal to FHWA to develop a uniform, national hot-mix asphalt training and certification program and another to document and communicate Superpave information. FHWA funding constraints eventually precluded further development of those concepts.

Figure 41 Principals of the Five Superpave Centers meeting at the Asphalt Institute, circa 1996. (L to R, David Anderson, Northeastern; Jon Epps, Western; Rebecca McDaniel, North Central; Ray Brown, Southeastern; Bob McGennis, South Central)

The Centers began cooperating in the summer of 1998 on the publication of joint newsletters as one means to ensure communication to a wide audience, some 6000 strong, about the evolution of the technology. The inside pages of these newsletters contained articles on issues of national interest and the outer pages were customized for each region. The design template for each region was the same with different colors reflecting the different parts of the country. The North Central Superpave Center took the lead on editing, designing and printing the newsletters while all the Centers shared in writing the articles. Eventually most Centers dropped out of the newsletter as funding became less certain or the Centers became less active. As of 2011, only two Centers are still collaborating on a joint newsletter, which is distributed to about three thousand people. Printed newsletters are being phased out and an electronic version is gaining in popularity.

The internet was also used extensively for communication from the Superpave Centers. All of the Centers developed a website to highlight the particular features and activities of their Center. In addition, the South Central Superpave Center set up a newsgroup to facilitate the sharing of information between the subscribers. Established in December 1996, the newsgroup had over 250 subscribers by December 1998.

One of the key missions of the Superpave Centers from their inception was to evaluate new pieces of equipment and associated test protocols. The Centers participated early on in the ruggedness evaluation of the Superpave gyratory, Superpave Shear Tester and Indirect Tensile Tester. Equipment and test protocol evaluations continue to this day as the Centers work on dynamic modulus testing, binder direct tension testing, the Asphalt Binder Cracking Device (ABCD) and more.

A 1997 AASHTO resolution (*22*) aimed to strengthen the support for the regional Centers. Citing the need for regional ownership of the Centers, the resolution encouraged financial participation by the states in their regional Center as well as state participation in the steering committees and supplying loaned staff to work at the Centers. The resolution also noted that FHWA had authorized the states to use 100% State Planning and Research SP&R) funds for their contribution. The level of funding support required was to be established by the individual regional steering committees.

5.4.4 TRB/NCHRP

Despite the fact that FHWA took the lead role in the implementation phase of Superpave, TRB was not out of the picture, by any means. TRB was deeply involved in the research needed to complete and refine the system through its National Cooperative Highway Research Program (NCHRP). TRB played a vital role later in the implementation phase when the severe budget cuts of TEA-21 curtailed much of the FHWA-funded work. One of the key steps taken to deal with the impacts of TEA-21 was TRB's co-sponsorship of the TRB Superpave Committee, along with FHWA and AASHTO, which was tasked with overseeing the implementation efforts. The TRB Superpave Committee will be discussed in Section 5.5.2. This section further outlines the key research activities at TRB/NCHRP.

5.4.4.1 Post-SHRP Asphalt Studies

As with any major research initiative, along with accomplishments, new needs and opportunities emerged as SHRP neared completion. Recognizing the potential benefit of supplementing the completed research, AAHTO's Standing Committee on Research (SCOR) recommended and approved NCHRP Project 20-35, *Plan for SHRP Follow-Up Studies* (*29*), as part of the NCHRP FY 1994 program. The project objective was to identify and prioritize research and development activities that should be pursued following the completion of SHRP, to build on completed research and help facilitate the use of SHRP findings.

Jon Epps and Peter Sebaaly of the University of Nevada Reno led the effort for the asphalt component of this project. They reviewed SHRP publications and communicated directly with individuals involved in the conduct, surveillance, management and implementation of its findings. Epps and Sebaaly identified 32 potential projects and provided detailed problem statements and research objectives. The next step involved the participation of 20 individuals representing various sectors of the highway community in the review and evaluation of the 32 prospective problem statements. As a result of a two-day workshop held in June 1994, the group reached a consensus on six high-priority research projects. The following, in descending order of priority, is a ranking of the projects (*29*):

1) Refinement of SHRP Gyratory Compaction Technique
2) Applicability of SHRP Binder Tests and Superpave to Mixes Containing Modified Asphalt Binders
3) Adaption of SHRP Binder Tests and Specifications to Recycled Mix Design
4) Aging of Asphalt Binders and Mixes
5) Validation of Superpave Pavement Temperature Models
6) Evaluation of Water Sensitivity Tests

For each of the high-priority research projects, the group provided details of the problem, proposed research, potential benefit to highway agencies, as well as estimates of funding and time required to conduct the research.

In addition to the high-priority research needs, the group identified and classified as highly important an additional research project entitled *Refinement of Binder and Mix Tests, Specifications and Models*, with funding to be provided by the FHWA. Finally, the group expressed support for other FHWA and NCHRP work underway or proposed, i.e., Superpave mix models and NCHRP Project 9-7, *Field Procedures and Equipment to Implement SHRP Asphalt Specifications*.

Since 1993, 45 NCHRP projects have been funded in the bituminous area, 25 of which directly addressed some "follow-up" element of Superpave. Total NCHRP project funding in the bituminous area between 1993 and 2010 was $26.8 million, 60 percent of which (~ $16.1 million) was directed to Superpave follow-up studies.

As is evident from the preceding, considerable funding has been directed toward the enhancement of Superpave. This does not include the considerable individual SHA efforts, i.e., work undertaken through the SPR (State Planning and Research) program. The significant post-SHRP research funding on Superpave is instructive. It is indicative of the broad scope and overly ambitious objective – conducting product-oriented research to facilitate the development of a readily-implementable solution to complex material behavior within a rigid time frame. The follow-up research was intended to address:

- the topics ignored or inadequately addressed (e.g., physical/mechanical properties of aggregates, construction practices);
- interesting/promising paths not taken (e.g., computerized tomography, acoustic emission)
- refinement, procurement and manufacture of equipment prototypes (e.g., BBR, gyratory)

5.4.5 User-Producer Groups

As implementation grew in importance towards the end of the research phase, thoughts were turning towards possible mechanisms to facilitate implementation. Tom Kennedy is widely credited with coming up with the idea of regional User-Producer Groups.

Kennedy was very familiar with the Pacific Coast Conference on Asphalt Specifications (PCCAS), which had been formed in 1956 to standardize asphalt grades in states in the far West (Alaska, Arizona, California, Hawaii, Nevada, Oregon and Washington). Through committee and regular meetings, the group had encouraged the adoption of standardized specifications for various asphalt products across the region.

Kennedy used the PCCAS model to encourage the formation of four similar groups across the country. The concept was to provide a forum where representatives of agencies and industry could work together to ease the growing pains associated with implementing a new technology. The North Central Asphalt User-Producer Group will be used as an example to illustrate how these groups came to be. Each region is a little different, but, like the regional Superpave Centers, have some commonalities.

In the summer of 1991, Tom Kennedy travelled to West Lafayette, Indiana, and met with a core group of people to discuss the formation and possible activities of a regional user-producer group in the Midwest. The invitees included representatives of the Indiana, Iowa and Minnesota DOTs and asphalt paving associations plus Dick Ingberg, the SHRP Regional contractor. (An earlier meeting between Kennedy, Ingberg, Gerry Huber, and Dave Holt and Richard Wolters from the Minnesota Asphalt Pavement Association in Minneapolis led up to this meeting.) Kennedy updated the group on the current status of the mix design and analysis system and the binder specification. He also outlined his vision of proposed activities:

- Catalog asphalts and aggregates used in the region along with performance;
- Identify problems experienced in specific areas and relate them to environmental conditions and/or the material properties identified in #1;
- Evaluate the mix design procedure and aggregate requirements;
- Evaluate the binder tests and specification limits (when available);
- Evaluate the mixture tests and specification limits (when available, interestingly, Kennedy noted this activity “may have to be delayed”);
- Sample test sections and monitor performance; and
- Build test sections to evaluate specific variables (in consultation with A-001).

Following this pre-planning meeting, the participants continued to discuss the potential for a regional group. By the end of 1991, they had formulated a plan and held an initial meeting in Chicago in September 1991. The group embraced the concept of forging a closer working relationship between the agencies and industry in the region. The group aimed to create a climate for change throughout the region. The overall mission of the North Central Asphalt User-Producer Group was to “improve the quality and cost-effectiveness of asphalt pavement.” In order to accomplish that one of their most immediate roles was to discuss, evaluate and implement the results of the SHRP Asphalt Research Program. In fact, SHRP implementation was the major focus of the group for many years. Later QA and other issues were added to the plate. Now that Superpave is the design procedure for hot-mix asphalt in the region, the group continues meeting annually to share information on other asphalt-related issues such as the MEPDG, pavement warranties, warm mix, performance-related specifications, intelligent compaction and more.

States and provinces in the Midwest and Canada were invited to join. After some jockeying around, the states corresponding mainly to the AASHTO region joined forces. These included Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, Ohio and Wisconsin with limited participation from the Dakotas, Manitoba and Saskatchewan.

The group was and is managed by a Management Committee consisting of one state and one industry representative from each state in the region. A subset of Management Committee members comprises the Executive Committee. In the early years, task forces addressed binder, aggregate and mixture issues.

Regional meetings were held once or twice a year, often in conjunction with a workshop on binder, mixture or other issues. Meeting attendees included chief engineers and upper management, asphalt engineers and middle management, and technicians and mix designers. One valuable feature of the NCAUPG meetings in the formative years was a one-day meeting for technicians. Though sometimes portrayed as “gripe sessions” in the early years, the meetings gave the folks who were down in the trenches working with the new equipment and test protocols a chance to share experiences, successes and failures. These meetings were instrumental in getting the technicians up to speed.

To this day, the meetings are generally structured to provide information about what is happening in the asphalt arena on the national, regional and state levels. These meetings are one of a very few opportunities to learn about regional issues and solutions. Travel restrictions and the state of the economy are hindering broad participation in the UPGs in many cases, however, the efforts to bring the regions together are continuing and the use of technology (webcasting, virtual meetings, etc.) is being explored to facilitate continued communication.

This group was definitely a key in obtaining the upper level management support that was necessary for implementation (though the AASHTO chief engineers meetings were also instrumental).

The NCAUPG also worked between meetings to further implementation efforts. Binder round robins were performed to examine testing variability, which was quite high when technicians were on the steep part of the learning curve. A group of binder suppliers and DOT personnel put together an asphalt supplier certification plan that eventually formed the basis for AASHTO PP 26 (now R 26), the "Standard Practice for Certifying Suppliers of Performance-Graded Asphalt Binder." A subset of states from the region began meeting in conjunction with the regional meeting to form the Combined State Binder Group (CSBG). This group of five (originally six) states cooperatively shares responsibilities for binder acceptance testing.

While the group had a number of successes and has continued in existence because of its intrinsic value, not every attempt met with success. For example, the group talked for years about standardizing mixture test procedures to facilitate reciprocity of certifications across state lines. Recommendations for reducing the number of variants of AASHTO test methods were developed and forwarded to the AASHTO Subcommittee on Materials for consideration. Despite many efforts in this regard, the standardization has not yet been realized on a regional basis, though there is some cooperation between individual states.

The North Central Asphalt User-Producer Group formation and activity was presented here as one example of what the UPGs accomplished. Each regional group was set up a little differently and tackled somewhat different issues, but all remain successful to this day, in different ways. It is, perhaps, a little ironic that the PCCAS was the model for the formation of the other regional UPGs but may have been the least successful in facilitating implementation of the Superpave asphalt products (though they have certainly been successful in other ways and states in the region are now coming on board).

5.4.5.1 Benefits and Expansion of the UPG Concept

The User-Producer Groups were, for the most part, very effective at establishing partnerships between agencies and industry within the regions, providing a forum for the exchange of information and facilitating the implementation of the new test procedures and specifications from the SHRP Asphalt Research Program. The fact that all of these groups are still meeting regularly, despite the current economy and difficulties in obtaining out of state travel approval for agency personnel, is evidence of their perceived value.

In the early days of the UPGs, travel for state and industry personnel, though not a foregone conclusion, was not as difficult as it is today. Nonetheless, for many people travel to a meeting within their region was easier to arrange than travel to a national meeting. The regional meetings gave these people who could not attend national meetings a place to meet and share information. They were (and are) an excellent venue for presenting information from a national level and making it relevant to the region.

A National Asphalt User-Producer Group was also active for several years. Its first meeting was held in Minneapolis in August 1993. Eventually the national group was superseded by the Expert Task Groups and was essentially, though perhaps not officially, disbanded.

Many states also formed their own individual User-Producer Groups. This brought the concept down to an even lower level and allowed more people to participate in the partnerships and information exchange. These are generally no longer active as PG binders have become the routine and issues are generally few and far between.

FHWA was instrumental in supporting the User-Producer Groups and helping them to be, in general, very successful. FHWA was very accommodating about sending speakers to the UPGs and providing whatever support they could for the groups.

5.4.6 Technical Working Group and Expert Task Groups

Expert Task Groups were used during the SHRP Program to provide technical review and guidance of the SHRP research. There were a number of ETGs formed; generally they were aligned with specific research contracts or were formed for a specific purpose.

At the end of SHRP, FHWA took on the responsibility for Superpave implementation. FHWA had used ETGs in the past as a method of including industry input to FHWA activities. For example, the FHWA sponsored a Volumetric Properties ETG chaired by John D'Angelo during the SHRP Program to gather information from the asphalt community regarding volumetric properties. This information was provided to the A001 contract and became a significant input into the Delphi process that was used to determine volumetric properties in Superpave.

A year before SHRP was scheduled to end, a meeting was held at the Old Colony Inn in Alexandria, Virginia, to make plans for completion of the research phase and ramping up of the implementation effort. All, or nearly all, of the states were represented at the meeting. Ted Ferragut of the FHWA remembers the atmosphere being somewhat tense in that state DOTs were concerned that FHWA would mandate use of Superpave. At the meeting, plans were made for test method standardization through AASHTO, and a pooled fund was organized for the purchase of new asphalt binder and mixture equipment. Also at that meeting, an Asphalt Technical Working Group (TWG) was formed. The TWG provided guidance for implementation of the SHRP Asphalt products.

The first meeting of the TWG occurred in 1993, and at that meeting Expert Task Groups were formed to provide more detailed technical guidance for adoption of Superpave. Initially two ETGs were formed, Asphalt Binder and Asphalt Mixture. These ETGs would be the responsibility of FHWA and would have representation from FHWA, state DOTs and industry. The ETGs were to provide advice on implementation of including test methods, equipment, specifications, etc.

At the first meeting in Alexandria and at the first TWG meeting that followed, Ted Ferragut remembers industry reluctance about adoption of the new specifications. The asphalt binder industry was relatively accepting of the new technology. The hot-mix asphalt industry was somewhat more reluctant.

It was clear then that the hot-mix industry was not on board. The reaction to the need for new equipment was strongly negative. Generally those contractors from states that were working in QA specifications and had responsibility for their own mix designs were more upset than those who came from traditional states, where the DOT did the designs and quality control.

Many of these QA contractors had recently built laboratories and now were being asked to discard their Marshall hammers, which cost $1200, and replace them with a gyratory compactor, estimated to cost $16,000. And since there was generally one laboratory at each hot-mix plant, the cost of implementation just for Level 1 mix design was considered excessive.

The mantra of the industry became "One size does not fit all". The position being that Superpave was not ready for implementation. Extensive additional research was needed before Level 1 (volumetric mix design) could be implemented. Over the course of several meetings there was in-depth discussion of equipment cost, the test protocols and the time to prepare samples.

The asphalt binder industry did not react as strongly against the new specifications as the hot-mix asphalt industry. One of the historic issues that face asphalt binder suppliers was the proliferation of specifications. Generally asphalt binder suppliers dealt with a larger market area than a hot-mix asphalt contractor, and having different specifications for different agencies caused additional costs. The Superpave binder specifications offered the possibility of a standard specification for all agencies, something the asphalt binder industry had been working toward for some years. As a result, although there were issues with the test equipment and test methods, as well as longer testing times, the asphalt binder industry worked toward resolution of the issues.

On the other hand, the hot-mix asphalt industry consisted of a large number of smaller companies that generally worked within a smaller geographic area. As the Superpave binder specification had issues, the Superpave asphalt mixture specifications also had issues with test equipment and test methods. In addition, the specifications had more restrictive requirements for aggregate properties than had generally been used. This was particularly true in areas that were dependent on gravel as the main source of aggregates. Depending on the primary source of aggregates and the current mix design specifications in a given area, the net effect of adopting Superpave mixture specifications was that industry would at best be not severely impacted by the new specification. In many areas there would be an impact on the cost of producing HMA because of changes to aggregates or asphalt binder content. As a result, many HMA contractors argued that the new specifications were not needed. Current practice was producing good performing pavements, and there was no need for change.

The Asphalt Mixture ETG provided a forum for dialogue. Over the course of ten to fifteen years, many issues were aired and changes implemented. Table 16 lists meetings of the Asphalt Mixture ETG that have occurred to date.

The Asphalt Mixture ETG provided input that led to research products and provided guidance regarding Superpave specification changes. Such input lead to the following NCHRP research topics:

- QC/QA with Superpave gyratory compactor
- Refinement of design gyrations
- Incorporation of reclaimed asphalt pavement
- Investigation of the restricted zone
- Investigation of VMA as a mix design parameter and setting of limits.
- Precision statements on gyratory compactor
- Simple performance test
- Investigation of laboratory aging method

Table 16 Asphalt Mixture Expert Task Group Meetings

	Place	Date
1	Atlanta, GA	Jun 24 & 25, 1993
2	St Paul, MN	May 26 & 27, 1994
3	Lexington, KY (Asphalt Institute)	Aug 24 & 25, 1994
4	Austin, TX	Feb 7 & 8, 1995
5	Reno, NV	May 16 & 17, 1995
6	Baltimore, MD	Sep 19 & 20, 1995
7	Phoenix, AZ	Mar 4 & 5, 1996
8	Seattle, WA	Sep 10 & 11, 1996
9	San Antonio, TX	Mar 4 & 5, 1997
10	Colorado Springs, CO	Sep 22 & 23, 1997
11	Orlando, FL	Mar 10 & 11, 1998
12	Baltimore, MD	Sep 22 & 23, 1998
13	Phoenix, AZ	Mar 18 & 19, 1999
14	Washington, DC	Sep 21 & 22, 1999
15	Washington, DC	Mar 28 & 29, 2000
16	Indianapolis, IN	Sep 11 & 12, 2000
17	Phoenix, AZ	Apr 3 & 4, 2001
18	Washington, DC	Aug 28 & 29, 2001
19	Denver, CO	Feb 20 & 21, 2002
20	Minneapolis, MN	Aug 28 & 29, 2002
21	Las Vegas, NV	Sep 16, 17 & 18, 2003
22	Washington, DC	Feb 11, 12 & 13, 2004
23	Washington, DC	Sep 27 & 28, 2004
24	Madison, WI	Jul 20 & 21, 2005
25	Denver, CO	May 11 & 12, 2006
26	Crystal City, VA	Sep 25 & 26, 2006
27	Denver, CO	Jul 24 & 25, 2007
28	Tampa, FL	Feb 25 & 26, 2008
29	Irvine, CA (Beckman Center)	Feb 26 & 27, 2009
30	San Antonio, TX	Sep 14 & 15, 2009
31	Irvine, CA (Beckman Center)	Feb 22 & 23, 2010
32	Madison, WI	Sep 21 & 22, 2010
33	Phoenix, AZ	Mar 17 & 18, 2011

An example of the role of the ETG is illustrated by the deliberations on design gyrations that occurred at the meeting held in September 1998 at Baltimore. NCHRP Project 9-9, being done by the National Center for Asphalt Pavements, was to investigate current design gyration values and make recommendations for change. The Asphalt Institute, working under the National Asphalt Training Center, reported the results of a study done for FHWA on the effect of design gyrations on mixture properties. Results of the two research projects were presented to the ETG. After discussion, the ETG recommended that Ray Brown and Mike Anderson, as principal investigators of the two projects, should have dinner together and return the next day with a joint recommendation, which they did. The ETG agreed with the recommendation, and it was forwarded to the AASHTO Subcommittee on Materials for balloting. It passed on the first ballot.

Similarly, the Asphalt Binder ETG dealt with issues regarding the asphalt binder specification. For example, the original SHRP research recommended the use of direct tension testing for the grading of modified asphalt binders. The SHRP researchers delivered a test method and proposed specification criteria. The ETG wrestled with testing issues and after several years decided that test variability could not be reduced sufficiently.

A new test method, Multiple Stress Creep Recovery (MSCR) was devised and proposed to the ETG. Ultimately the Binder ETG concurred with the research and forwarded a recommendation to the AASHTO Subcommittee on Materials

The role and purpose of the Asphalt Mixture and Asphalt Binder ETGs remain as valid today as in 1993 when they were first formed. These two ETGs continue to meet and review information and provide guidance for research needed and specification changes for HMA to the AASHTO Subcommittee on Materials

5.4.7 Asphalt Institute

As implementation plans developed in 1992 it became apparent that the implementation would exceed the personnel resources of FHWA, and a decision was made to develop a National Asphalt Training Center, as discussed in Section 5.2.2.4. The role of this Center would be to develop training courses and manuals necessary to disseminate information about the new specifications and provide state DOTs with sufficient information to implement Superpave within their state.

Also, as the SHRP Program was drawing to a close, it became apparent that many implementation questions required additional investigation. These issues included:

- What is the correct laboratory compaction effort?
- Can mix be designed with a gyratory and controlled with a Marshall hammer?
- Can crumb rubber modified asphalt binders be tested for PG grade?
- Are flat and elongated specifications too restrictive? Too permissive?
- What about fine aggregate angularity?

There were a host of questions coming from state DOTs, the asphalt binder industry and the hot-mix contractor industry. A mechanism was needed to address such questions if implementation had a hope of succeeding. This mechanism was addressed, in part, through the contracts with the Asphalt Institute.

In September 1992, FHWA had awarded a three- year contract for the NATC to the Asphalt Institute. A follow-up five-year contract, NATC II, was awarded in September 1995.

Training was a large portion of their work. The first task was to develop training materials and manuals. Hands-on training was required for the first wave of DOT engineers and lab technicians. Courses in binder testing and mix design were taught beginning in July 1993 at the Asphalt Institute laboratories in Lexington, Kentucky. By the fall of 1996, 18 binder and 18 mix courses had been taught, training over 700 engineers and technicians from agencies, industry, FHWA and universities. Pilot one- and two-week courses on the mix analysis system were also developed and presented under NATC II. The Institute continued to offer the binder and mix training after the second contract expired (on a fee basis).

In the early days of Superpave implementation, there were numerous wildfires of opinion that ran through the industry. Such controversies included:

- Tender zone – mix could not be compacted because it is tender.
- VMA – Superpave mixtures could not be designed with our aggregates to meet VMA requirements.
- Gyratory Compactors – different compactors produce different air void results for the same mix.
- Binder Contents – some people felt mixes did not have enough asphalt binder in them.
- Compaction – difficulties in achieving field compaction were thought to result in high permeability with these mixes.

The Asphalt Institute helped develop information that defused many of these controversies or provided information for making changes to the specifications. Such areas included:

- Reducing the number of traffic levels from seven to five.
- Removing the summer temperature provision of the N_{design} table.
- Changing the N_{design} table to the current levels.
- Compacting specimens to N_{design} instead of N-max.
- Changing short-term oven aging from 4 hours to 2 hours.
- Vacuum degassing asphalt after PAV (Pressure Air Vessel) conditioning.
- Refining the Rolling Thin Film Oven protocol regarding scraping of the bottles.
- Developing protocols for Direct Tension testing of asphalt binders.
- Refining the Bending Beam Rheometer protocols to establishing time zero.

These and other issues required investigation, recommendation for change, and modification of manuals and training material.

The Asphalt Institute was involved in Superpave-related activities from other sources as well as the NATC. They were involved in NCHRP Project 9-7, *Field Procedures and Equipment to Implement SHRP Asphalt Specifications*. This project had the combined goals of demonstrating how asphalt binder and hot-mix asphalt could be designed and produced under the new Superpave specification.

By the end of the second NATC contract in September 2000, the implementation of Superpave was quite mature. Most states had adopted the Superpave binder specifications. Many had adopted the Superpave mixture specifications. The FHWA and the NATC worked in cooperation with AASHTO (especially the Subcommittee on Materials) and the AASHTO Lead State implementation effort. Together the stage was set for adoption of the results of Strategic Highway Research Program.

5.4.8 NAPA and the Construction Industry

It is widely felt that the material suppliers and highway contractors did not play a large enough role during the research phase of Superpave. While there were various industry representatives on committees, industry was largely missing in the defining stages of the research. Those industry representatives who were involved were generally at the highest levels. The technical people from industry were brought in fairly late in the game when the products had largely been framed. Earlier and deeper industry involvement in the research phase, in retrospect, would probably have facilitated implementation later.

Many felt that industry was going to have to implement a system that they had little hand in shaping. This, plus the general resistance humans have to change, created some serious apprehension in the industry. There were inevitable cost impacts associated with implementing Superpave that industry would have to bear – and pass along to their customers. Thousands of people needed training, new equipment would have to be purchased and some long-standing procedures would likely need to be changed as well. It is easy to understand how those who had not been involved in the process would be reluctant to fully embrace the changes that were coming.

On the other hand, there were many in the industry that recognized that change was necessary. The performance problems that had prompted the SHRP Asphalt Research in the first place had not been resolved on a national level. (There were some individual states that had investigated issues like premature rutting and had instituted their own changes in factors like crushed faces and gradations.) Left unchecked, these problems could seriously erode asphalt's market share. While Superpave might not be perfect, it was seen as an improvement over what had been done in the past.

In fact, industry did play a large role in the later stages of the research phase in forcing the shift from binder chemistry to mixture properties. Gerry Triplett, President of the Asphalt Institute had reportedly tried to point out to the SHRP Executive Committee the shortcomings of a binder chemistry approach. This was perceived by some in the states that the binder suppliers were defensive and trying to protect their interests. People like Charlie Potts, Roger Yarbrough and Campbell Crawford eventually helped bring about the change in emphasis by focusing on the importance of mix properties.

The fragmentation of the asphalt industry also probably played a role in the attitudes towards SHRP. There was no single entity looking over and involved in the research. There was no coordinated industry involvement. Industry involvement was (and is to this day) usually voluntary and unfunded, so there must be a benefit to being involved to justify the time and expense required for participation. Today industry plays a larger role in the research process through the National Center for Asphalt Technology, participation in TRB committees and NCHRP projects panels, and other means.

Industry was dealing with a number of other momentous changes around the same time SHRP implementation was building steam. Many states were moving towards quality control/quality assurance (QC/QA) type specifications. In fact, Superpave and QC/QA specifications were implemented simultaneously in several states.

Industry representatives frankly state that the industry was not very technical at the time SHRP was initiated. They had been using "cookbooks" provided by the state specifications. The implementation of Superpave forced them to develop a deeper understanding of their products. Around the same time, states' budgets began shrinking and experienced personnel were retiring. All these factors together led to industry becoming much more technically proficient than they had been before and in many cases more knowledgeable than the DOTs.

When implementation became a real feature on the horizon, many in industry saw things that did not make sense to them. They had not been validated in the field. The pooled-fund equipment buy may have been helpful for the states, but industry as a whole did not have the equipment. When equipment became commercially available, it raised the awareness of the industry.

Awareness was also raised through meetings like the TRB Annual Meeting, the Association of Asphalt Paving Technologists meeting and the user-producers groups. Those contractors whose personnel were able to participate in such meetings were better prepared to implement Superpave because they had gained some insights into what was coming. Companies with a corporate vision to be leaders and innovators also had a leg up. Good relationships – partnerships – between agencies and industry also helped overcome the reluctance to change.

There were also inevitable personality conflicts surrounding implementation. Many in industry saw FHWA as being heavy-handed, even dictatorial. Use of Superpave had not been officially mandated by FHWA, but sometimes it felt as if it was. More flexibility and an acknowledgement that there were problems that still needed to be addressed would also likely have helped facilitate implementation. Eventually FHWA seemed to loosen up and partner more with the end users to make adjustments in the system through the ETGs, working with the UPGs and other collaborative efforts.

Another facet of the industry, besides material suppliers and contractors, was heavily involved in implementation – the equipment manufacturers. Without their efforts to produce the needed equipment, implementation would not have been possible.

The first article procurement was challenging for some of the equipment manufacturers, especially the gyratory manufacturers. The equipment specification was put out for bid, then withdrawn when it was realized that the actual angle of the prototype gyratory used at the Asphalt Institute was not 1° as planned but was in fact 1.27°. Other changes in the equipment came along later in the implementation phase. The binder direct tension device had to be completely redesigned after the initial version had severe limitations; to this day direct tension is rarely used.

Manufacturers had to seriously investigate the potential market for equipment before deciding to pursue manufacture. The volume of the market was very uncertain, especially since changes were being made in the system up to and beyond the end of the research phase. Construction equipment manufacturers also had to gear up since higher traffic level Superpave mixes required heavier pavers and higher efficiency rollers to compact and lay these mixes. They met the challenge and were a key element in contractors being able to produce Superpave pavements.

Eventually industry in most states embraced Superpave technology. In fact, in some places, industry encouraged wider use of the technologies by the states as well as local agencies. Once they had invested in training and equipment, they preferred to use it and maintain one system, rather than a combination of old and new. Industry also participated in various efforts, like the development of the Approved Asphalt Supplier Certification procedure, in partnership with DOTs.

5.4.9 SPS-9 Projects

As mentioned earlier (5.4.1.3), the AASHTO Task Force on SHRP Implementation supported the ongoing research under the Long-Term Pavement Performance program and was instrumental in urging AASHTO to step in to fund continued efforts when the FHWA discretionary funds that had supported LTPP (among other activities) were virtually eliminated under TEA-21. For Superpave, the main LTPP activity was the so-called SPS-9 experiment.

The Specific Pavement Studies experiments within LTPP involved the construction of test sections with controlled variables designed to evaluate specific pavement features. This was in contrast to the General Pavement Studies (GPS) sections, which were existing pavements. The SPS-9 program was intended to monitor the performance of pavements constructed using the newly developed Superpave specifications. The first pilot SPS-9 sections were constructed in 1992 in Indiana, Wisconsin and Maryland before the research phase had officially ended. Additional pilot projects were constructed in Minnesota and Kansas in 1993. (Wisconsin constructed a total of three pilot SPS-9 projects.) Each site consisted of multiple test sections to allow comparison of the existing state practice to Superpave. Additional sections could be added at the state's request.

The sites were monitored for rutting and other pavement distress and traffic levels. Later, additional SPS-9A sections were constructed to compare various binder grades and SPS-9B sites were constructed to evaluate various mix design parameters. The Asphalt Institute and some Superpave Centers assisted with mix design for many of these projects. Unfortunately, the budget cuts imposed by TEA-21 severely curtailed the monitoring of these sites under LTPP and few SPS-9A or 9B sites were constructed.

The sites that were built, however, proved to be extremely beneficial in a number of ways. These experiments were closely watched in the early years. They showed that states could implement the new specifications and contractors could construct pavements using the new designs. They also provided data that was used to encourage further implementation. For example, one of the Wisconsin test sites provided mix design data that was used in the training materials prepared by the National Asphalt Training Center (5.4.7). These training resources were used not only by the Asphalt Institute but also by the Superpave Centers, state training organizations, universities and others. A 1995 paper presented at the Association of Asphalt Paving Technologists meeting in Portland, Oregon, reported on the design, construction and early performance of six of the seven pilot SPS-9 projects. There was great interest expressed by the AAPT audience in seeing factual data from the projects.

Although the thorough, long-term performance evaluation initially envisioned through LTPP did not happen, the SPS-9 sites did show other states that the new Superpave material specifications and mix design requirements could be successfully implemented. States constructing these sites typically did internal follow-up to supplement the LTPP monitoring activities. (For example, as of 2011 Indiana is still following its SPS-9A project constructed in 1997.) The opportunity for focused nationwide evaluation of the field performance of Superpave mixes, however, was lost due to a lack of resources.

5.4.10 Universities

A limited number of universities were involved in the SHRP Asphalt Research program and even fewer were selected to be Superpave Centers. While these universities were able to offer their students, especially graduate students, a chance to get involved in Superpave on the ground floor, the majority of engineering schools around the country had had little exposure to the program.

If Superpave were to become the accepted method for selection of materials and design of mixes, the engineers of the future would need to develop familiarity with the technology. As the training grounds for these budding engineers, the faculties at the more than 200 engineering schools in the US (and beyond) needed to understand and teach Superpave technology.

FHWA recognized the need to train undergraduate engineering students and sponsored the development of training materials for undergraduate and graduate level materials courses. These course materials were developed by NCAT and were distributed to Technology Transfer Centers in the states, state materials engineers, FHWA division offices, industry and the Superpave Centers on CDs. From there, the CDs have been widely distributed nationally and internationally. Superpave technology is now incorporated routinely in engineering and technical curricula.

Availability of Superpave testing equipment has also increased greatly since the implementation phase began. In some cases, this equipment has been provided by industry to ensure that engineers graduating from those schools have the opportunity to become familiar with the technology they will be expected to use in practice.

Auburn University also started a popular professors training course at NCAT in 1994. It has been taught every year since. A less intensive course was provided by the North Central Superpave Center for Indiana universities with funding support from FHWA.

Universities in most states have become increasingly involved in using Superpave technology in their teaching and research, as well as helping state DOTs provide training and certification for their employees and industry.

So, from a limited number of schools involved in the SHRP asphalt research, the number of universities providing Superpave training and experience has increased dramatically over the last 18 years. Any reputable school with a curriculum involving asphalt is now instructing students in Superpave technology and, usually, providing lab experience with the tests and equipment.

5.4.11 Conferences and Workshops

The number of conferences and workshops dedicated to various aspects of Superpave technology is indisputably large, but impossible to determine. Conferences have been held at all levels from international to national, regional, state-wide and local. They have been sponsored by individual agencies, industry groups (state paving associations, NAPA, the Asphalt Institute, International Center for Aggregates Research and many more), the Association of Asphalt Paving Technologists, the Superpave Centers, the User-Producer Groups, regions, FHWA, TRB and many others.

Early on in the implementation process, however, a few national conferences were held that deserve particular mention for helping to spread the word about the status of Superpave implementation and its challenges. In particular a major conference was held in Reno, Nevada, from October 24 to 28, 1994, to hear the results of the SHRP research as well as implementation efforts. (A transcript is available as an electronic appendix (Appendix E) to this report.)

By late 1993 and early 1994 final reports from the different asphalt research contracts were printed and became available to the asphalt community. Their sheer volume was overwhelming. The reports consumed about three feet of shelf space. It was clear that very few in the community could or would devote the time to digest them and extract the important information.

This major conference was initiated by the Asphalt Technical Working Group and was funded by FHWA. The conference was sponsored by the FHWA, the Nevada Department of Transportation, AASHTO, TRB, the Asphalt Institute, NAPA and the International Society of Asphalt Pavements. Total attendance was 460 representing a broad cross section of the U.S. asphalt community and about 20 foreign countries.

Sessions went from 8:00 am to 6:15 pm. On Wednesday evening four parallel tracks of supplementary sessions were held from 7:30 pm to 10:00 pm. From Monday noon until the end of Wednesday the researchers presented results of their research program. Thursday was devoted to implementation issues from the point of view of FHWA, state DOTs, asphalt binder suppliers, contractors and AASHTO (specifications). Friday morning was devoted to two case studies from the points of view of the mix designer and the state DOT.

Continuing in 1996 until 2000 biannual workshops were sponsored by FHWA, with various co-sponsors including the Asphalt Institute, TRB, state DOTs, the Superpave Centers and other industry groups. The themes and locations of the workshops are shown below.

- *Open House on Superpave 2000*, August 21-22, 1996, Indianapolis
- *Superpave: Today and Tomorrow*, April 21-23, 1998, St Louis
- *Superpave: Building Roads for the 21st Century*, April 10-12, 2000, Denver

The objective of the *Superpave 2000 Open House* was to demonstrate how states were implementing Superpave in order to share experiences and encourage other states to adopt the new technology by the year 2000. Indiana was the host state for the conference because of its aggressive and largely successful implementation program. (INDOT credited part of its success to the fact that it had members on the Binder ETG and Asphalt TWG, in addition to Chief Engineer Don Lucas being involved in the SHRP Executive Committee.) The workshop included site visits to paving projects (on county roads, showing that Superpave was not just for high volume roads only) and the North Central Superpave Center. Presentations described the current national status of binder and mix implementation, WesTrack performance, the industry perspective on implementation, warranties and more. Representatives from Florida, Maryland, Arizona and Indiana also reported on the progress of implementation in their states.

Superpave: Today and Tomorrow was intended to develop better understanding of the Superpave system, research and implementation efforts ongoing in 1998, and changes being made to the system. The conference was held in St. Louis, Missouri, in part because of the important role Joe Mickes, MoDOT's Chief Engineer, played as chairman of the TRB-SHRP Committee and the involvement of MoDOT in the Lead State Teams. One important element of this conference was the presence of information booths and vendors who displayed the newest equipment.

In the opening session, Don Steinke, chief of the Highway Operations Division of FHWA, gave a presentation where he openly acknowledged some of the problems that had been encountered by states implementing the new technology and approaches to resolving those problems. First he cited a number of successes with implementation, such as the fact that most states had implemented the binder specification and that local agencies (including Albuquerque, NM; Los Angeles County, CA; St. Louis County, MO; and Maricopa County, AZ) were using Superpave. Then he addressed the problems – permeability in Florida, flushing in Indiana and rutting at WesTrack. Steinke noted that the Florida DOT had worked with FHWA to solve the problem of increased permeability in Superpave mixtures by increasing the lift thickness to four times the nominal maximum aggregate size to allow room for the additional compaction necessary. The flushing of several miles of newly paved interstate in Indiana had generated a lot of talk about the failure of Superpave. Investigation into the cause, though, revealed a number of factors not related to Superpave – most importantly several days of rain and inadequate drying of the aggregates during mix production. Steinke commented that both Florida and Indiana remained fully committed to implementing Superpave despite the problems they had encountered. Lastly, Steinke acknowledged that coarse-graded Superpave mixes at WesTrack had shown early rutting and he reported on the preliminary findings and recommendations of the forensics team (summarized in 5.6.4.3).

Much of the rest of the conference focused on contractors and industry and the issues they were facing. Problems and concerns were raised and, when possible, resolutions were offered. Sessions dealt with mix design, material selection, construction, and performance testing and modeling. Notably, Ron Sines from the New York State DOT and Chuck Deahl of Compaction America offered suggestions for dealing with compaction problems in the field.

Dale Decker reported on a survey of twenty contractors who had experience working with Superpave mixtures. He noted that while the performance had been good to date, there had been some problems with production and placement. NAPA had produced a document offering *Superpave Construction Guidelines* to help deal with these issues. The survey showed that existing binder and aggregate suppliers were able to provide materials meeting the new requirements. At the mix design stage, achieving the VMA was challenging for about half those surveyed. For most contractors, production of the mixes was "business as usual," but field compaction was more difficult, especially with higher compaction requirements for some mixes to eliminate permeability issues.

Speakers from both the asphalt refining and aggregate industry expressed general support for the implementation of Superpave technology but noted the large investment that would be required in some cases to produce the materials. Refiners had challenges to face in producing different grades of binder at the same terminal and were finding they needed more tanks to store the different grades separately. Gene E. Chew, from American International Refinery, stated that the Asphalt Institute and its member companies were "absolutely committed" to the implementation. Mark Towe of the National Stone Association also expressed support "provided that current concerns and issues can be resolved satisfactorily." He commented on the large investments some aggregate producers would potentially need to purchase different crushers and other equipment to meet the shape and gradation requirements.

The last of these biennial conferences was held in Denver, Colorado, in April 2000. *Superpave: Building Roads for the 21st Century* highlighted the changes that had been made in the AASHTO specifications for Superpave. It also included discussions of ongoing industry issues.

Kim Snyder, then chairman of the National Stone Association, reported on research that was sponsored by the NSA through the International Center for Aggregates Research (ICAR) to address some of the issues of concern that Mark Towe had mentioned at the previous conference. Projects focused on the requirements for flat and elongated particles, fine aggregate angularity, the restricted zone and VMA.

Sessions at this conference were centered on selecting materials, design and production, construction, and performance and the future. Materials suppliers, contractors, DOT personnel and researchers shared their experiences with QC/QA, mix design, laydown and compaction and more. Some of the changes that had been implemented by this point in time included reduction in the number of design and temperature levels, establishment of a 20-year design life, reduction in the design compaction level for mixtures deeper in the pavement, and changes in the binder and mixture conditioning protocols. The conference showed that there were still items that needed attention and refinement, but that Superpave mixtures could be produced and were performing well. The message was that work was underway to continue the refinement of the system in the future but that the framework was sound and workable.

Countless other conferences, workshops and open houses at all levels and for a wide range of audiences helped to spread the word that implementing a new system would take work but that it could be done. Experiences were shared amongst the agencies, industry and researchers to help the process along.

5.5 IMPLEMENTATION AT RISK – THE TEA-21 YEARS

In 1999, the Superpave world was about to change and very few people saw it coming. It started with the Transportation Equity Act for the 21st Century (TEA-21). That legislation clearly restructured highway research funding in a way that nobody had anticipated. TEA-21 abruptly stopped discretionary funding for the SHRP Implementation Program. Why? Many reasons surfaced, but most would attribute it to the stakeholders possibly getting too complacent about the funding and failing to show Congress the benefits that had already accrued.

AASHTO and FHWA partnered immediately after passage of the bill to develop a “Save SHRP” program. Everyone agreed that the SHRP products, especially from Superpave and LTPP, were nowhere near complete. Without support, Superpave implementation could grind to a halt immediately just as many of the states were coming to grips with the binder and mix specifications and making changes to their practices.

5.5.1 Background

The Federal-aid Highway Program has historically included discretionary funding for research and technology transfer by the FHWA to support innovation among state and municipal departments of transportation and the private sector of the highway community. The passage of the Transportation Equity Act significantly changed the discretionary funding levels and shifted responsibilities for program definition and management. With the dramatic reduction in FHWA discretionary funds, many continuing research programs of national importance – Superpave among them – were threatened with delay or cancellation (*30*).

Recognizing the seriousness of the situation, AASHTO committees and task forces developed contingency plans for continuing research and implementation, especially for those SHRP research findings currently being implemented. The AASHTO Board of Directors, after carefully considering these contingency plans, passed resolution AR-5-98, on November 8, 1998 (*23*). Key provisions of the resolution pertaining to Superpave called for:

- The allocation of National Cooperative Highway Research Program funds to support high-priority aspects of a program of Superpave development and deployment;
- The establishment at TRB of an “oversight” committee to advise AASHTO and FHWA on the content, conduct and financial needs of this program; and
- Development of a long-range plan for the Superpave program.

In 1999 the state DOTs were expected to award approximately 3,000 asphalt paving projects that would employ the new Superpave tests and specifications. This represented about 46% of the hot-mix tonnage placed by the states. By 2000, nearly all states were expected to adopt the binder specifications and most would be using the mix design procedures. While much had been accomplished, there are still some gaps in knowledge and key elements of Superpave that needed refinement. For example, more work was required to:

- Relate asphalt binder specifications to field performance, especially for modified binders;

- Sort through complex Superpave performance-related tests and prediction methods to identify a "simple" procedure that could be used to confirm design values, and guide quality control and quality assurance;
- Validate the Superpave procedures and specifications by looking back at some Superpave mixes that had up to five years of field service;
- Assure that specification parameters and tolerances are set so that cost-effectiveness and product quality are maintained at an appropriate balance.

In this far-reaching resolution (*23*), the AASHTO Board of Directors stated that $5.6 M in support of Superpave and other hot-mix asphalt research would be required as follows:

FHWA – Superpave Projects Continuation		$2.200 M
NCHRP Project 9-19	$1.700 M	
NCHRP Project 9-20	$1.500 M	
SHRP Lead State Program (includes Superpave among others)		$0.050 M
TRB Program Support		$0.150 M

NCHRP Projects 9-19 and 9-20 enabled completion of research begun by FHWA to develop simple performance tests for Superpave-designed mixes (9-19) and an HMA performance-related specification through the WesTrack experiment (9-20). The dollar amount and the speed of processing new contractual arrangements kept the Superpave program going with no stoppages or delays.

5.5.2 TRB Superpave Committee

Heretofore, Superpave implementation had been steered through the FHWA Technical Working Group and the Expert Task Groups. On December 8, 1998, as stipulated in AR5-98, TRB, FHWAA and AASHTO formed the Superpave Committee (E1006) at TRB. The Committee membership is shown in Table 17.

This Committee was different in that it had no control of funds and only had the power of recommendations. It did, however, hold the purse strings on the Expert Task Groups. The AASHTO Subcommittee on Materials had become very dependent on the recommendations from the ETG to support the development of standards and continuation of the ETGs was considered essential to future progress.

The first meeting of the TRB Superpave Committee was held in March 1999. At that meeting, the Committee fully endorsed the need for national coordination and oversight at this critical stage of Superpave implementation. The Committee reviewed the program of Superpave research then under consideration by AASHTO for inclusion in the FY 2000 work program of NCHRP and recommended 11 projects with a total cost of $3,275,000. The Committee also initiated discussion of a long-range plan for Superpave development and deployment (discussed in Section 5.5.5) and the reconstitution of the Superpave Mix and Binder Expert Task Groups, formerly supported by FHWA.

Table 17 Members of the TRB Superpave Committee

Name	Organization
Joseph A. Mickes, Chair	Missouri DOT
David Anderson	Pennsylvania State University
Martin F. Barker	City of Albuquerque, NM
Wade Betenson	Utah DOT
Frank Danchetz	Georgia DOT
Fred M. Fehsenfeld, Sr.	The Heritage Group
John Haddock	Purdue University
Eric E. Harm	Illinois DOT
Dallas N. Little	Texas A&M University
Donald W. Lucas	Indiana DOT
Paul Mack	New York State DOT
Joe P. Mahoney	University of Washington
Charles R. Marek	Vulcan Materials Company
John B. Metcalf	Louisiana State University
Gale C. Page	Florida DOT
Charles F. Potts	APAC, Inc.
Douglas R. Rose	Maryland DOT
Byron Ruth	University of Florida
Dean C. Weitzel	Nevada DOT
Y. T. Yarnell	Wilbur Smith Associates
Mike Acott (Liaison)	National Asphalt Pavement Association
Ken Kobetsky (Liaison)	AASHTO
Bernard M. McCarthy (Liaison)	The Asphalt Institute
Vincent F. Schimmoller (Liaison)	FHWA
Sarah Wells (Liaison)	Transportation Association of Canada
Greg Smith (Liaison)	American Road and Transportation Builders Association
Ted Ferragut (Consultant)	TDC Partners
Neil F. Hawks (Staff Rep.)	TRB

Since meetings of the Superpave Committee were only planned for every six months, TRB asked staff from FHWA and AASHTO to meet much more frequently to support the work of the Superpave Committee. Termed the TRB Superpave Support Group, the members from all three organizations had experience in Superpave technology and program management. They proved invaluable as a continuing resource to the Committee. The Support Group immediately pulled together a comprehensive list of projects for consideration by the Committee, prior to evaluation by AASHTO's Standing Committee on Research and ultimately by NCHRP.

The Committee, however, was not a rubber stamp to the Support Group recommendations. The Committee recommended deferral of four projects that they believed did not need to be pursued immediately. The Committee also deferred the Support Group's request for additional research on moisture sensitivity of Superpave mixes, pending results from other NCHRP work.

AASHTO's Standing Committee on Research (SCOR) reviewed in detail the Committee's slate of projects and recommended funding. They clearly saw the need for Superpave continuation and approved 13 projects outright and one project for contingent funds. The only project not approved was a $1.0 M request to support a second FHWA Superpave mobile laboratory. SCOR recognized the contribution the mobile laboratories had made to Superpave implementation and suggested that the TRB Superpave Committee explore other possible funding techniques, including direct industry and state support. In April of 1999, the AASHTO Board of Directors adopted the SCOR recommendations.

After reviewing the SCOR and Board of Directors' decisions for FY 1999 and FY 2000, the Committee immediately worked on a preliminary slate of eight new and five continuation projects for the NCHRP FY 2001 program, including the development of project statements.

To address the unresolved issue of moisture damage sensitivity of asphalt mixtures, the Committee sponsored a national focus group to consider the issue and suggest a course of action. In July 1999, nearly 30 national experts explored the issue of moisture damage in asphalt pavements. They collectively reviewed past and current work, and then broke into two smaller focus groups. Both groups independently agreed that moisture damage was a national issue and recommended the continuation of research. A problem statement was drafted for consideration by the Committee in upcoming meetings.

Of critical significance at the second meeting of the TRB Superpave Committee in June 1999, the Committee approved the formation of two Expert Task Groups under TRB auspices. The Mix ETG would focus on mix and aggregate issues, the Binder ETG would focus on binder issues. The Committee also reviewed and discussed additional concepts for the long-range Superpave plan, looking at potential projects, budgets, and a timeline.

The committee was operational between 1998 and 2004, holding 11 meetings. Each meeting was followed by a letter report from the chair to the Executive Director of AASHTO and Administrator of the FHWA.

5.5.3 *The ETGs Under TEA-21*

The newly constituted Mix ETG met in September 1999 and reviewed a full slate of outstanding technical issues, including key aggregate issues. The ETG established task forces that would monitor the conduct of FHWA research being supported with NCHRP funds. The ETG also provided recommendations on the draft long-range plan prepared by the Superpave Support Group and the FY2001 project statements. Finally, the ETG established a communication procedure among the members of the Superpave Committee, the Binder ETG, the Superpave Lead State Team and the AASHTO SOM.

The ETGs continued to meet and advance the technology through the TEA-21 years with the support of TRB.

5.5.4 *Survival*

So, with the support of AASHTO and the states and the cooperation of FHWA and TRB, the work on Superpave implementation was able to proceed. Significant NCHRP funding supported additional research to refine the system and pick up what would otherwise have been lost because of FHWA's reduced funding. In a sense, the states were again taking charge of their research products.

The TRB Superpave Committee was addressing the key elements of AR 5-98 (*23*):

- The Superpave development and deployment program was moving forward with the support and participation of AASHTO, FHWA, the individual state DOTs, and the hot-mix paving industry;
- Mechanisms to monitor and coordinate Superpave and related hot-mix asphalt research had been established; and
- An effective long-range financial and technical plan for completion of Superpave implementation and deployment was under development.

In many respects, 1999 was a landmark year. Superpave implementation had survived – not entirely intact, but beyond the 'doomsday' vision that many had when TEA-21 was passed. It had funds, it had projects, it had steering and technical committees.

For 2000 and beyond, the TRB Superpave Committee believed it was important to focus on four key issues and continue the push to:

- Assure that the remaining Superpave technical issues were properly identified and addressed;
- Assure that the financial estimates required to complete Superpave were justified;
- Integrate this information into a long-range plan that would become the blueprint for completion of Superpave; and
- Assure that sufficient emphasis was placed on a communications, publications, training, and outreach program that would effectively deliver Superpave to the ultimate users.

The Committee foresaw no immediate remedy to the severe reduction of discretionary resources within FHWA. In the absence of a remedy, the Committee continued to provide recommendations to AASHTO and FHWA on the content and conduct of a financially constrained program.

5.5.5 Superpave 2005

So in 1999, with leadership from AASHTO, FHWA, and NCHRP, the Transportation Research Board had established the TRB Superpave Committee to review work plans of AASHTO and FHWA research, advise on objectives and tasks, identify missing components, and suggest coordination of activities. Expert task groups (ETGs) for binders, mix/aggregate, and communications/training were formed to assist the committee.

"We had everything but a final goal. We needed to focus on when we would be done," noted Superpave Committee chairman Joe Mickes. "We had been at this now since the early 1980s. We were not going to keep going forever. That led us to develop a longer-range plan – *Superpave 2005*." The TRB Superpave Committee also decided that it would sunset by 2005 to enforce its timeline (*31*).

Four major goals were identified that would round out the implementation phase of the program. They would define completion of the program.

> *Goal 1. Superpave will recommend binder type (including modified binders) and mixture proportions based on environmental and loading conditions and pavement design*

> *Goal 2. Superpave will predict the ability of a mix to withstand rutting, fatigue, thermal cracking and moisture damage.*

Goal 3. Superpave will integrate the binder and mix requirements into a performance-based construction quality control specification system

Goal 4. Superpave will be clearly understood by public and private-sector engineers, technicians, and contractors through initial and continuing training and outreach programs.

Goal 1 focused on ensuring that the binder specifications would be blind to modification. The key to Superpave performance-based binder specification is that the physical properties required for the binders are the same for all grades but the temperature at which those properties must be attained should fit the specific climatic conditions at the paving location. This was always a goal of the research phase of the program.

The Superpave binder specification at the time accommodated virtually all unmodified binders, but not all modified binders. In 2002, the Binder ETG continued to review NCHRP and FHWA-managed research on laboratory test methods to better characterize modified binders. To investigate the relationship of these laboratory measured characteristics to performance, 17 states and 20 industry groups agreed to join in an FHWA-administered pooled-fund study using the FHWA's Accelerated Loading Facility (ALF) to test twelve lanes of Superpave mixtures made with various modified binders. While some of the research is now complete and standards have been developed for revised tests and specification tables, the revised test methods are still not widely used. Recent research at FHWA to develop the Multi-Stress Creep and Recovery (MSCR) test with application for modified and unmodified binders seems to be generating more attention than previous test protocols and may eventually be widely implemented.

Goal 2 focused on performance predictions. A major objective of the Superpave system was the prediction of the field performance of specific HMA mixtures based upon laboratory tests. Researchers developing the Mechanistic-Empirical Pavement Design Guide (MEPDG), under NCHRP 1–37A, incorporated a refined Superpave indirect tensile test and a recalibrated Superpave model for thermal cracking into their work. This helped link pavement design and performance prediction to actual laboratory derived mix design values for low-temperature cracking properties. Many states are now in the process of or have already implemented the new pavement design procedures.

Also in 2002, three candidate simple performance tests for the Superpave volumetric mix design methods were identified under NCHRP Project 9-19. Test equipment manufactured by the private sector was evaluated under NCHRP Project 9-29. The Asphalt Mix Performance Tester (AMPT) is now being purchased by many states through a pooled fund and looks like it will be widely implemented, in support of both mix design and MEPDG implementation by the states. It remains to be seen how many industry labs purchase the equipment; that will no doubt be a longer process.

With committee support, research on the fundamental mechanisms of moisture sensitivity (stripping) is continuing through FHWA-managed research at the Western Research Institute in Laramie, Wyoming. NCHRP continues to tackle this difficult issue through a variety of projects looking at the moisture susceptibility of both HMA and WMA.

Work is ongoing on Goal 3, which focused on the relating binder selection and mix design to construction and performance. Performance -related specifications link key HMA parameters under the control of the contractor to laboratory determined test values, which can be used to predict the life of the as-built pavement to the as-designed pavement. A recently completed NCHRP project (9-22, *Beta Testing and Validation of HMA Performance-Related Specifications*) developed software derived from the MEPDG to allow these comparisons and develop pay factors based on the anticipated pavement life compared to the design life.

The final goal, the Communications goal, focused on getting the word out through communications. Everyone had agreed that communications during the first phase of implementation had been key to informing the broad based community as well as the technical community.

The Communications and Training ETG was formed in 2001 to promote understanding of the Superpave system. The ETG was fully operational in 2002. It supported the development of a history of Superpave, an integrated mix design manual, a Superpave electronic newsletter, and support of national conferences. The ETG worked with the Transportation Curriculum Coordinating Committee (TCCC, a pooled-fund effort of DOTs supporting efficiencies in training) to assist in the development of Superpave-related training programs. The TCCC released two revised Superpave training modules in early 2011.

In support of this goal, NCHRP funds were approved for NCHRP Project 9-33 to develop the final Superpave communication and training product – a compendium of revised mix analysis methods, software, and manual.. The manual was published in 2011 as NCHRP Report 673, "A Manual for Design of Hot-Mix Asphalt with Commentary."

While the Committee recognized that Superpave was perceived as a product for use by state DOTs, in reality the Superpave system was equally applicable to city, county and local road and street networks. In 2002, the committee asked the Superpave Support Team to develop a Superpave workshop for attendees at the 8th International Conference on Low-Volume Roads in June 2003, in Reno, NV. Many states have now embraced Superpave fully and have removed Marshall, Hveem or other mixes from their specifications; local agencies have increasingly used Superpave mix designs as well. In many places, industry has helped to encourage local agencies to adopt Superpave. The Superpave Centers have also assisted in this effort through training and technology transfer. The Center at Penn State hosted a workshop in the northeast in 2001 that led to a white paper on use of Superpave for low-volume roads (*32*). Slowly but surely, use of the technology is becoming pervasive.

Funding uncertainties brought about by the failure of the national legislature to agree on a budget led to a long gap between meetings of the TRB Superpave Committee in 2003-2004. The TRB Superpave Committee held its eleventh and final meeting on December 6, 2004. The committee had earlier agreed to sunset in 2005. Future enhancements would fall under the banner of improved asphalt technology rather than fulfillment of the Superpave system.

5.6 TECHNOLOGY ADVANCEMENTS AND CHALLENGES DURING IMPLEMENTATION

It has been noted earlier that many of the SHRP products related to Superpave were not fully ready for wide-scale implementation. This section will summarize some of the technological challenges and advancements that were made during the implementation phase. It will also start to give a picture of the state of the practice today.

5.6.1 Binder Testing and Specifications

There had been approximately 15 versions of the PG binder specifications prepared and modified during the research phase. Eventually, the framework and guiding concepts were set, and they are still in use today, for the most part, though there have been refinements in some of the testing procedures, application of the specifications, proposed new test methods, etc.

The pooled-fund equipment buy was instrumental in getting the technology into the hands of the state DOTs but not industry. The real push to get industry outfitted to perform the testing came when it became obvious that the states were going to specify PG grades. As the number of pieces of equipment in use increased, issues began to crop up. For example, early round robin testing showed that the variability in testing results between labs was quite high – the acceptable range of test results between multiple labs could be over 50% in some cases. There was concern over this variability, but increased training and experience, plus greater attention to calibration, brought the variability down significantly. There were also some differences between different brands of equipment that came to light. For instance, there were differences in how time zero was defined and the shape of the beam supports between different brands of BBR. Once these differences were discovered, they could be resolved, so they were really minor glitches in implementation.

More significant problems were discovered very early on with the direct tension test device. The initial device used an air-cooled test chamber, vertical specimen mounting and a laser to detect breakage of the specimen. Obtaining reliable and repeatable test results with this configuration proved to be extremely difficult; so difficult, in fact, that the device was not included in the pooled-fund equipment buy. The test was pulled from the specifications and the equipment was completely redesigned. A fluid bath, horizontal specimen mounting, and detecting breakage by the drop in resistance to pulling made the test much easier to perform and more repeatable. The test was added back into the specifications but is optional and rarely used.

One concept behind the PG specifications that was somewhat less successful than planned was the concept that the specifications would be blind to binder modification; that is, that modified and unmodified binders could be tested the same way and held to the same standards. This was an attractive concept to many DOTs, which had been struggling with how to specify modified binders generically in a low-bid culture. It was soon recognized, however, that the originally proposed test protocols did not adequately characterize the enhanced performance generally provided by modified binders. Several research projects were conducted to address this issue, most notably NCHRP 9-10, *Characterization of Modified Asphalt Binders in Superpave Mix Design*. The research team, led by Hussain Bahia of the University of Wisconsin, Doug Hanson of NCAT and Mike Anderson of the Asphalt Institute, offered several test protocols that would better characterize modified binders. The research team recommended replacing the DSR rutting parameter $G^*/\sin\delta$ by the viscous component of creep stiffness, G_v; replacing the DSR fatigue parameter $G^*\sin\delta$ by a fatigue life parameter, Np, measured in a repeated cyclic loading test in the DSR; and evaluating the glass transition temperature for low-temperature cracking. The research also developed a Particulate Additive Test (PAT) to determine if the modified binder contains more than 2% particulate material, in which case mixture testing is required to evaluate the modifier. A storage stability test was also developed. Despite the fact that most of the proposed tests used existing equipment, with modifications, the protocols were not adopted nor are they widely used today.

FHWA has continued working with a Multi-Stress Creep and Recovery (MSCR) test to better account for the effects of modified binders. This test protocol also uses the DSR, with modifications to the software, and does seem to be gaining greater acceptance.

There have been other efforts to develop improved binder testing protocols, but to date they have not been widely accepted. For example, research efforts have investigated the binder aging protocols in an attempt to address some perceived shortcomings with the current RTFO and PAV protocols. The Binder ETG remains on the forefront of the continuing efforts to refine the system.

In addition to equipment and testing issues, there have been issues with interpretation of the meaning of the test results and selection of the proper binder grade. For example, early versions of the LTPPBind software frequently recommended -34 grade binders for wide swathes of the northern United States. Producing such soft binder grades was challenging for refiners and often the binders were much softer than had been used in those areas previously. Research at instrumented pavement sections in Canada and elsewhere helped to demonstrate that the original recommendations were overly conservative. Eventually, LTPPBind was modified with new low-temperature algorithms that yielded more reasonable estimates of the required low-temperature grade. Earlier FHWA guidance had advised to carefully consider whether use of such a low temperature was appropriate.

As another example of the interpretation of the data, some colorful maps were prepared to show the binder grades recommended for different areas of the country. In short order, it was determined that such maps were not detailed enough to be used to select project-specific binders. They could be used as rough guides for marketing purposes only. In some cases, state agencies made “liberal” interpretation of the binder selection criteria to reduce the number of PG grades in the state.

5.6.2 Mixture Testing and Specifications

One of the earliest sticking points on the mixture side of Superpave implementation was the restricted zone. This area of the gradation specification had been included as a warning that gradations passing through that zone could exhibit tenderness problems during construction. The recommendation to avoid gradations passing through that region was based on previous experience with Marshall mixes. There were states, however, that had good experience with some mixes that passed through the so-called restricted zone. Resistance to implementing this zone was high, especially in states like Georgia that had those mixes they felt performed well. Some states never did institute the restricted zone. Eventually the warning was removed from the specifications entirely.

Another contentious issue was the range of fine aggregate angularity (FAA) values recommended for different traffic levels. Because natural aggregates were frequently not able to meet the FAA requirements, states were facing increased use of manufactured sands. In some states, aggregate suppliers and industry associations warned that they might not be able to produce enough material with high enough angularity. Vast shortages were predicted for some areas of the country. There was also concern in the industry that the often higher angularity requirements on both the fine and coarse fractions could lead to increase equipment and processing costs and increased waste of non-spec material (particularly excess fines). Despite the cries of doom, great shortages did not materialize. Existing material suppliers were able to adjust, for the most part, and produce the required materials. There were – and in some cases still are – issues with excess fine aggregates being generated, so industry and agencies are working on identifying beneficial uses for these materials. Finer mixes and small nominal maximum aggregate sized mixes (4.75 mm) are being used more widely, which is lessening the problem to some extent.

Early Superpave mixes for high volume roadways were typically designed as coarse mixes; the need to avoid the restricted zone, which tended to favor fine mixes, contributed to this trend. Coarse mixes were uncommon in many states prior to Superpave, so their use represented a great departure from standard practice. Results from WesTrack and other research, however, demonstrated that fine-graded Superpave mixes could perform well – in some cases better than coarse mixes. (See Section 5.6.4.3.) Consequently, many states have started using more fine-graded mixes, even for high traffic volumes.

Large quantities of reclaimed asphalt pavement (RAP) were accumulated (and are still accumulating) in some parts of the country, particularly in urban areas. The original Superpave mixture specifications did not disallow the use of RAP but there was no guidance on how to incorporate RAP. Besides, contractors and agencies were trying to come to grips with a new set of material and mix design requirements; they were reluctant at first to introduce another variable. The FHWA Mixture ETG issued some interim guidance on the use of RAP in 1997, based on previous experience with Marshall mixes. The use of RAP in Superpave slowly began to increase. In early 2001, the findings of NCHRP 9-12, *Incorporation of Reclaimed Asphalt Pavement in the Superpave System*, were released and revised AASHTO specifications were adopted. Within a few years, the use of RAP had generally increased back up to pre-Superpave levels in most parts of the country. The use of higher percentages (25-50%) of RAP is still an issue in 2011 and another FHWA ETG has been established to investigate and promote the use of higher RAP contents.

The Superpave Gyratory Compactor is standard laboratory equipment now. There have, however, been changes in that equipment as well. Differences were noted between the densities produced by different brands or models of gyratory compactors. As these were investigated, it was discovered that the actual angle of gyration applied to the mix inside the gyratory mold could vary, especially as mix stiffness varied and affected the machine compliance. This led, eventually, to specifying the angle of gyration based on measuring the angle inside the mold rather than on the outside. Devices that could simulate the presence of a mix and allow measuring the internal angle have been developed and are now required in the AASHTO specifications for calibrating the internal angle.

5.6.3 Performance Testing

As discussed previously, the ultimate vision for Superpave was to base all mix designs on volumetric principles, then do testing for higher traffic volume roadway designs to ensure that the designed mixtures would perform as needed. The testing was to facilitate the prediction of the distresses that would be likely to occur for those mixes under the traffic and environmental conditions at the project location. A three-tier design system was described with increasing levels of testing for higher traffic volumes. This vision has not yet been fully realized.

The proposed testing was to be conducted in the Superpave Shear Tester (SST) for high and intermediate temperature properties (rutting and fatigue) and Indirect Tensile Tester (IDT) for low-temperature properties (thermal cracking). (The FHWA, Superpave Centers and a handful of labs around the country were outfitted with the SST and IDT.) The data obtained from these tests was then input into software that would predict the rutting and cracking likely to develop. While the low-temperature prediction models were generally acknowledged to correlate fairly well to thermal cracking, the rutting models in particular appeared to have problems. In part this may be credited to the fact that the projects developing the models and the project developing the tests were not as well integrated as they should have been. In addition, the equipment was expensive and fairly complicated to run. The end result was that the tests and the models were never widely used. Both the SST and IDT have been used successfully for research purposes, such as in NCHRP 9-10 and 9-12. In addition, the tests and the software have been used for the design of a few high profile warranty projects. It is safe to say, however, that the higher level design methods have not been widely implemented.

In addition, other research efforts since SHRP have moved in another direction. The MEPDG for flexible pavements incorporates the dynamic modulus of the mixture. Other NCHRP projects have led to commercially available equipment – the Asphalt Mixture Performance Tester (AMPT) – to conduct the dynamic modulus and other test methods. States are now in the process of purchasing the AMPT and implementing the MEPDG. The Models ETG is still in existence and is overseeing the implementation and eventual refinement of models to predict pavement distress and performance.

5.6.4 Construction

As the use of Superpave mixtures increased, reports began to surface of construction issues in the field. In most cases, these issues were related to the changes in the gradations, stiffness and production temperatures of the mixtures. Many of these could be resolved by relatively minor adjustments in procedures. In other cases, the problems pointed to issues that required greater adjustments.

For example, in areas where Superpave aggregates were coarser or harder than the previously used materials, contractors reported some increased wear in some equipment – such as flights in drums, paddles in batch plants, paver augers and screed plates. Other production issues included changes in the drying time and efficiency, greater aggregate breakdown and VMA collapse with coarser mixtures, higher production temperatures for modified mixes in particular, the need for more cold feed bins to accommodate the large percentages of coarse aggregate, etc.

At the paving site, increased segregation was observed with some coarser mixes. Handwork was often reported to be more difficult, especially with modified binders. Modified binders also tended to stick more to truck beds.

The biggest construction issues, however, were definitely related to compaction. Coarser, stiffer, modified mixes were harder to compact in the field. In most cases, compaction could be improved by changing some production parameters and construction techniques. Keeping the mixes hot was found to improve compactability markedly, so higher production temperatures, the use of tarps and insulated truck beds, and keeping rollers up close to the paver to achieve compaction while the mix was hot were all found to be effective techniques to improve density. Changes in rolling patterns and the types of compactors used were also successful in many cases. But not in all.

5.6.4.1 Changes in Compaction

There were many reports from the field of increased mix tenderness. This tenderness interfered with compaction of the mixes. The tenderness seemed to differ from traditional mix tenderness that seemed to be related to the aggregate gradation (and was the raison d'être for the restricted zone). The particular tenderness reported with Superpave mixes seemed to be related more to the mix temperature; typically there was a range of temperatures, which varied between projects and mixes, where compaction could be more difficult and sometimes additional roller passes actually decreased the density. Research eventually showed a relation to the total fluids content in the mixes. Contractors often learned how to work around the tender zone by doing most of the rolling immediately behind the paver, then staying off the mat until the mix cooled below the tender zone. Once the mat cooled sufficiently, finish rolling would be applied. Sometimes changing the types of compactors also helped; often pneumatic rollers could be used through the tender zone.

The tender zone was not reported on all projects. Estimates at the time suggested that fewer than 25% of Superpave projects exhibited the tender zone. Today the tender zone is almost never discussed. Contractors have learned to avoid it or deal with it as needed.

5.6.4.2 Florida Permeability Issues

The Florida DOT set a pretty aggressive schedule for implementation of Superpave mixtures. They had been experiencing problems with premature rutting and other distresses, so welcomed the potential to improve performance with Superpave. Ten Superpave projects were constructed in 1996 in the state. Achieving the required density was challenging in many cases. Shortly after construction, several of the projects began to exhibit permeability problems (*33*). Specifically, water could be observed seeping into or out of the pavement. This raised concerns that there could eventually be stripping problems on these pavements.

FDOT immediately began investigating the case of the permeability, how to measure it and how to prevent its occurrence on future projects. This eventually led to recommendations to increase the lift thickness to allow room for the coarser aggregate particles to reorient under the rollers, thus improving the density and reducing permeability. In keeping with their role as a Lead State, FDOT was willing to "go public" with the problems and their solution, so the greater community could learn from their experience. The recommendation to increase the lift thickness to four times the nominal maximum aggregate size for coarse mixes was adopted by many other states as well as Florida.

5.6.4.3 WesTrack

In 1995, under a contract awarded by the FHWA, 26 test sections were placed on a 3 kilometer test track in the Nevada desert. WesTrack, as it was known, was primarily established to develop performance-related specifications for hot-mix asphalt. The test sections were designed to evaluate the effects of varying binder contents, gradations and in-place air voids on mixture performance. Since these mixes were designed according to the Superpave mix design requirements, a secondary objective of the contract was to provide early verification of the performance of Superpave mixes. Automated (i.e., driverless) triple trailer trucks were used to apply accelerated traffic loading to the test sections. In two years, 4.5 million ESALs were applied to the pavement, which is a very high rate of loading.

Early failure of some of the test sections, including the coarse-graded mixes that were expected to perform well, raised concerns among the highway community about the mix design system. After the application of some 2.7 million ESALs (Spring 1997), nearly every section had rutted, some severely. Fatigue cracking had also appeared in many of the test sections, although conventional wisdom would say fatigue and rutting typically do not happen in the same mixtures because of their conflicting mechanisms. The mix design procedure favored coarse mixes, but WesTrack suggested that these mixes, in particular, would be prone to performance problems. Because of the severe rutting and fatigue cracking, ten sections were replaced in May-June 1997; eight using the original coarse-graded design but with a more angular coarse aggregate and two using standard Nevada DOT mixes with polymer modified binder.

Surprisingly, most of the replacement sections failed even faster than the original sections had failed. Significant rutting began to occur in as few as five days. This increased the concerns that there might be something wrong with the Superpave mix design system. The asphalt community was abuzz with rumors and speculation. Prompt action needed to be taken to dispel the rumors before the whole Superpave system was derailed.

To examine the results at WesTrack and determine the likely cause(s) of the problems in the coarse-graded mixes, FHWA assembled a forensics team consisting of academicians, state highway engineers, consultants and industry personnel. Two FHWA representatives also participated in the deliberations. (The forensics team membership is shown in Table 18.)

Table 18 WesTrack Forensic Team Members

Name	Organization
Ray Brown	NCAT
Erv Dukatz	Mathy Construction Co.
Gerald Huber	Heritage Research Group
Larry Michael	Maryland State Highway Administration
Jim Scherocman	Consulting Engineer
Ron Sines	New York State DOT
John D'Angelo	FHWA (Liaison)
Chris Williams	FHWA (Liaison)

The mixes had been designed for 10 million design ESALs. Because of the accelerated rate of loading, however, the loadings were very concentrated. Had the traffic continued at that rate for a full 20 year design life, the total loading would have exceeded 75 million ESALs (*34*).

The forensics team developed a plan of laboratory testing to evaluate the properties of the in-place mixtures. Testing included determining the gradations and volumetrics of field samples, conducting SST and loaded wheel tests, evaluating extracted binder and more. These results were compared to results of tests during production. After extensive analysis and debate, the forensics team issued a final report (*35*). The majority opinion expressed in the report was that the premature rutting observed was primarily due to a relatively high binder content. This high binder content was caused by high VMA in the aggregate structure which in turn required a high design binder content to fill the voids. This was exacerbated by over-asphalting during production. Mixes with higher dust to binder ratios performed better than those with lower dust to binder ratios, likely because of the greater effect the higher dust content had on the mastic stiffness. The final report conceded that mixture volumetrics alone might not be enough to guarantee the performance of asphalt mixes under high traffic volumes.

A subset of the forensic team members (Gerry Huber, Jim Scherocman and Erv Dukatz) offered another explanation (*35*). They felt the thickness of the pavement structure played a role in the observed distresses. The tangential sections were designed with thinner cross sections than in the curves and the mixes in the curves did not rut as much as in the tangents. Their theory was that coarse-graded mixes experience more strain in the mastic than fine-graded mixes because there are fewer points of contact between the aggregates. In thin pavement sections, these mixes will experience high strain that can explain both the rutting and fatigue cracking observed.

Recommendations were made to improve Superpave mix design based on the lessons learned at WesTrack. Many of these were eventually codified in the AASHTO mix design standards. Key among the recommendations:

- The dust to binder ratio was increased for coarse-graded mixes (from 0.6-1.2 to 0.8-1.6).
- A maximum VMA should be established to reduce the likelihood of high design binder contents – for coarse-graded mixes the maximum VMA was recommended to be no more than 2% above the minimum value.
- Volumetric properties, including VMA, should be measured on plant-produced mixes.
- The N_{design} should be based on a 20 year design life, regardless of how long the pavement is expected to perform. In other words, the rate of traffic loading, not just the total traffic, has a great effect on pavement performance. By basing all designs on a 20 year design life, the rate of loading can be taken into account.
- A performance test should be performed on mixes for high volume roadways after the volumetric mix design is completed. Although the loaded wheel testers and SST "showed some merit," the search for a reliable rutting performance test continues.

With the issuance of the final report, plus mix design guidelines based on the WesTrack experience, some of the furor and concern about WesTrack abated. Case studies of good performing Superpave mixes also helped to defray the concerns and show that the results at WesTrack were not representative of what was happening under normal traffic conditions.

5.6.4.4 Asphalt Institute Field Survey

In response to widespread rumors about Superpave construction projects in about 1996, the Asphalt Institute reviewed 86 of the estimated 93 Superpave projects constructed in 1996. The projects ranged in size from small test sections to large-scale construction projects. The review was conducted by a variety of means from phone calls to in-person interviews. The review attempted to identify how many field projects exhibited some kind of construction problem, what those problems were, what factors might have contributed to the problem and how they were addressed.

The survey concluded that roughly one-third of the projects constructed in 1996 exhibited some construction issue. This was not felt to be unreasonable when implementing a new system. The issues were mainly in terms of:

- Meeting density requirements (compaction);
- Meeting VMA requirements;
- Segregation;
- Shoving under the intermediate roller;
- Mixes with modified binders sticking to pneumatic tires on rollers ("pick up");
- Mixes sticking to truck beds.

The report also noted that many of these issues were resolved in the field during construction by changing the practices (changing roller patterns, using different rollers in different positions, watching mix and mat temperatures, etc.). Other remedies were also offered, such as increasing lift thicknesses to allow for better compaction, changing the design gradation or increasing the crushed content to increase VMA, changing release agents and more.

The real significance of this document (*36*) was that it showed two-thirds of the Superpave projects had no issues during construction, even though these mixes were still relatively unfamiliar to most states and contractors. The responses from the states showed several instances where contractors expressed a preference for Superpave over Marshall mixes. This helped to dispel some of the doom and gloom that had been accumulating in light of some widely publicized (or rumored) problems. The report also offered practical suggestions for dealing with similar problems, if they occurred, giving practitioners some guidance they could rely on.

5.7 WHERE ARE WE TODAY?

The preceding discussion has highlighted some of the changes that have occurred in Superpave as implementation has progressed and has given some hints of where we stand today, nearly 18 years after Superpave implementation began in earnest. To summarize the current situation, the following is offered.

5.7.1 Binders

The PG binder specifications and tests are almost universally used around the country. They have been incorporated in state specifications and are now widely used by local agencies and in private work as well. In large measure, this widespread implementation has been driven by industry and their reasonable reluctance to maintain two systems.

The goal of adopting a uniform binder specification across the country was not realized in total. A large number of states – more than half – have adopted what are known as “PG+” specifications, particularly to accommodate modified binders, where they start with the “pure” PG specifications and add additional tests or requirements. Force ductility is a commonly used plus, but there are many differing ways to run that test. Phase angle requirements are also frequently specified. Many states require particular forms of binder modification (such as SBR) or disallow some types (such as polyphosphoric acid). Several states in the southeast have adopted a PG67-22 binder grade to match more closely to the AC-30 binders they used pre-Superpave.

The Binder ETG and other groups continue to work on refinement of the binder tests and specifications but the original framework and concept is still largely in force. Many hope that implementation of the new MSCR test will remove the need for the PG+ tests used in many states and promote a more uniform system.

5.7.2 Mixtures and Construction

The Superpave mix design system is now widely used but not in every state. California has recently moved to implement Superpave but Tennessee and Nevada are among the few states that do not. In many of the states that did adopt Superpave mixes, the use has now become routine and often the mixes are no longer called Superpave – they are simply hot-mix asphalt, or sometimes are known as gyratory mixes.

As use of Superpave has become routine in individual states, the use by local agencies and in private work has also increased. In some cases, owners may not realize that they are getting Superpave mixes, but that is what contractors provide. The use of RAP has increased and continues to increase. Other recycled materials, such as shingles, are also being used.

Issues related to aggregate do not appear to be as numerous or troublesome as they were initially anticipated, by some, to be. Construction issues related to Superpave mixtures in particular have largely been resolved (though of course there are still issues, as, of course, there were before implementation of the Superpave system).

The Mixture and Aggregate ETG is also continuing to look to improve asphalt pavement performance. The use of Warm Mix Asphalt is coming on very strong and is the focus of a great deal of research and field implementation.

5.7.3 Models

Work continues on evaluating models to predict pavement performance based on measuring fundamental engineering properties. The focus has shifted away from the models pursued during SHRP, however, to those recommended in the MEPDG. The Models ETG continues their oversight role in this regard.

The MEPDG models have been incorporated into mix design and performance-related HMA specifications (through, for example, NCHRP Projects 9-19, 9-22, 9-30A, and 9-33A). The final report for NCHRP Project 9-22 (NCHRP Report 704, "A Performance-Related Specification for Hot-Mix Asphalt") and its associated software allow states to compare the as-built to the as-designed materials to assess the impacts of construction QA on the performance life of the pavement. Additionally, work continues to define develop models for top down cracking and reflective cracking for future integration in DARWin ME, the AASHTOWare program developed from the MEPDG.

5.7.4 Construction

Superpave has become business as usual for contractors across the country. While construction issues continue – and will likely continue as long as we continue to construct asphalt concrete pavements– those issues are typically not attributed to Superpave mixes. They are simply a fact of life. The improvements that are widely recognized as resulting from the implementation of Superpave, such as greatly reduced rutting and improved resistance to thermal cracking, have allowed us to see other problems that probably existed before but were overshadowed by more pressing, more visible problems. Work continues to resolve issues like longitudinal joint construction, segregation, etc.

Chapter 6. Lessons Learned and Conclusion

This section discusses some key lessons learned through the SHRP Asphalt Research Program and the implementation of its products. These lessons were gleaned from interviews with those involved and gathered by the research team as they put together all the various inputs.

6.1 CONTINUALLY REFINE ANTICIPATED PRODUCTS AND DELIVERABLES

Special Report 202 identified the SHRP Asphalt Research Program as an *applied research program* with well-defined products and deliverables, viz., “specifications, tests . . . needed to achieve and control the pavement performance desired.”

The 1986 Brown Book further defined these deliverables as a performance-related specification for asphalt binder and an asphalt-aggregate mixture analysis system. The 1987 Contracting Plan for SHRP Asphalt Research approved assigned responsibility for the development of the performance-based asphalt binder specification to the A-001 contractor and that for the performance-based specification for AAMAS to the A-006 contractor. (As discussed above, later programmatic changes transferred this responsibility to the A-001 contractor). Finally, as the research progressed from 1988 onward, a dialogue among the program sponsors, the stakeholders in the highway community, and the various oversight bodies led to a consensus that the specification for an AAMAS should be broadened to a specification for asphalt-aggregate mixtures, to include a mixture analysis system, mixing and compaction procedures, and performance tests.

Once the research began, these well-defined products and deliverables provided a clear metric against which to measure progress in the various elements of the program. Early on (through about mid-1991) research proceeded, by plan, along many paths and with the conduct of considerable basic research; one example of this is the assessment of the influence of asphalt chemistry on its performance. However, from mid-1991 to the program’s end in 1993, the scope was continually narrowed, with the goal of shifting finite resources to work elements that were judged by the program’s technical management and oversight bodies to be most critical to achieving the defined deliverables. Such decisions were often unpopular, and it is true that promising research activities were terminated or reduced in scope because they were judged—sometimes incorrectly in retrospect—to be unproductive or of peripheral value.

6.2 REALISTICALLY DEFINE TIME AND RESOURCES

The highway community is now accustomed to FHWA, NCHRP, SHRP2, and other organizations routinely conducting multi-million-dollar research projects. It is easy to forget how remarkable such projects are as compared to the typical $50,000 projects of the mid-1980s. Aside perhaps from the AASHO Road Test, nothing like SHRP had ever taken place in highway research. This change, of course, was by design—those who planned SHRP and secured its funding successfully argued that the targeted problems were so large and deep-seated that only a program devoting massive funding to their solutions would suffice.

The SHRP Asphalt Research program budget was $50 million, still a truly significant amount, even after taking into account 25 years of inflation. Perhaps more noteworthy, though, was the requirement to spend this amount and deliver the two performance-related specifications within a period of only five years, roughly mid-1988 to mid-1993. To meet this requirement, it was necessary for SHRP to solicit proposals and award contracts for the projects shown in

Tables 3 and 4 between 1988 and 1990 and for the selected contractors to carry out the research and develop the products between 1988 and 1993.

Was this allocation of time and resources (money) realistic? To answer this question, it is necessary to judge how well SHRP delivered the two key products of the asphalt research program. A complete asphalt binder specification and its supporting tests and equipment were delivered in 1993 and, as discussed elsewhere, have been successfully implemented and adopted into U.S. practice. What was adopted looks much like what was delivered in 1993, although it is undeniable that much of the binder specification's implementation involved further refinement and enhancement of the original SHRP product. So the asphalt binder specification may be considered a qualified success.

The situation is not so sanguine for the asphalt-aggregate mixture specification. What appeared to be a complete specification, supporting tests and equipment, and software were also delivered in 1993 (see, for example, report SHRP-A-407). What proved ready to implement and adopt in routine practice was limited, however, to the Superpave volumetric design method, whose hallmarks are the use of the gyratory compactor and well-defined aggregate and mixture volumetric property specifications. While this limited design method has proven robust and extremely useful in improving asphalt pavement performance, it cannot be considered a true performance-related asphalt-aggregate mixture specification. The original performance tests and equipment for permanent deformation and fatigue cracking were too complex and expensive, though they remain in use today for research applications. The Superpave software developed to provide transfer functions and distress prediction models did not function as needed and was not salvageable by a well-funded FHWA research project in the 1990s, though this project did deliver usable performance tests for permanent deformation and fatigue cracking in the 2000s (at a combined cost to FHWA and NCHRP of almost $5 million). Ultimately, it required the development of the MEPDG between 1996 and 2004 (at a cost of more than $9 million in NCHRP funding) to provide the wherewithal for the performance-related asphalt-aggregate mixture specification envisioned by SHRP. This specification has only now become available through NCHRP Projects 9-19, 9-22, 9-22A, and 9-33A.

So the SHRP Asphalt Research program delivered perhaps 65% of the key products identified by the program's planners. Considering everything, this is a solid if not spectacular return for the time and resources committed to the program. Would more time and resources have made a difference? Probably not, for in hindsight, it can be argued that the completion of a viable asphalt-aggregate mixture specification required model development and computing power that were not available in the early 1990s. This technological lack, not time or money, was likely the true limiting factor for SHRP. And it should be noted that the successful development of the MEPDG also required pavement performance data gathered through the SHRP and FHWA LTPP for model calibration and validation. Such data were not available in sufficient quantity and quality until the late 1990s and early 2000s.

Even so, the question can be asked whether a different allocation of the available funds during SHRP might have delivered a more finished, viable asphalt-aggregate mixture specification. Interestingly, the authors of both Special Report 202 and the 1987 Contracting Plan for SHRP Asphalt Research provided direction on this issue. To quote the contracting plan: "In the asphalt area, the original report, "America's Highways: Accelerating the Search for Innovation," clearly put the dominant focus on asphalt binders. Subsequent discussions by the AASHTO Task Force, the AASHTO Select Committee on Research, and the National Research Council's SHRP Executive Committee have reinforced this initial vision, placing the primary emphasis on research to improve asphalt binders." Knowing what we know now, it is clear that diverting funds from the asphalt binder specification to that of the asphalt-aggregate mixture specification during SHRP would have jeopardized the former without significantly improving the later. The planners' direction was prescient.

6.3 CONTINUALLY CHALLENGE BASIC HYPOTHESES

As stated in Chapter 3, the overall objective of the SHRP Asphalt Research program, as articulated in Special Report 202, was to improve pavement performance through an increased understanding of the chemical and physical properties of asphalt cement in the context of its use in pavement. From the beginning, then, investigation of the relationship of asphalt pavement performance and asphalt chemistry was given a co-equal place in the research program with the relationship to asphalt physical behavior. Indeed, the earliest "strawman" specification for asphalt binder developed in 1989 included criteria for nitrogen and acid factor contents to help select materials with adequate resistance to moisture sensitivity.

However, succeeding versions of the SHRP strawman specification and the present AASHTO specification M 320, Performance-Graded Asphalt Binders, which developed from the strawmen, rely exclusively on rheology to define the expected performance of asphalt binders. Volume 1 of Report SHRP-A-367 describes the reasons for this ultimate shift from the co-equal status of chemical and physical properties as the basis for the asphalt binder specification: "The original goal of the physical-chemical correlations was to relate asphalt chemistry to pavement performance. This goal was found to be exceedingly optimistic and unrealistic. Physical properties determine the response of a pavement to traffic loading, and there are endless combinations of chemistries that can result in a given value for any of the performance-related binder physical properties. Thus, although it may be possible to define the physical properties needed to provide a certain level of performance, there are innumerable asphalt chemistries that can produce the desired asphalt physical properties. Relationships between asphalt chemistry and pavement performance could undoubtedly be developed empirically by simply correlating chemical properties with percent cracking and other performance-related properties, but this would provide little basic understanding of the real role of asphalt chemistry in determining binder performance."

That asphalt chemistry, which encompasses topics such as crude oil sources and refining methods, could be correlated with asphalt pavement performance was a basic hypothesis of the SHRP Asphalt Research program—remember Bob Farris's assertion that asphalt "wasn't as sticky as it used to be." Given the emphasis on this hypothesis in Special Report 202 and the Brown Book, SHRP might well have pursued development of a solely or predominately chemical-based specification that would have ultimately yielded an unworkable product. Instead, a working consensus developed in SHRP that challenged this hypothesis. This consensus led to development of the rheology-based binder specification, which has proven both workable and practical.

6.4 CLEARLY APPRECIATE PROBLEM SCOPE, SIZE AND COMPLEXITY

For any research program, the size of the problem to be solved must be understood. Careful forethought and planning are essential to a successful outcome of the research. Resources, both financial and human, are tied to the estimation of the problem size. A problem that is "discovered" to be of a larger size than anticipated can lead to insufficient resources and cause serious compromises to the research. If the scope of the research is clearly understood prior to commencement, then either sufficient resources can be dedicated or a revised scope can be developed to match resources.

In the lead-up to the Special Report 202 there was a meeting held in Dallas, Texas, at which a minority of participants expressed concern that asphalt mixtures were being disregarded in favor of asphalt chemistry, to the detriment of the proposed research effort. The majority remained convinced that mixture design, within the context of then current parameters (aggregate properties, asphalt content, air voids, VMA, etc.), would be supplanted by discoveries to be made.

When Special Report 202 was issued in 1984 there was no mention of asphalt mixtures. It was not until the Brown Book was published in May 1986 with proposed research contracts that asphalt mixtures were added. The Brown Book talked about development of models to predict rutting, fatigue cracking and low-temperature cracking of HMA but had only a limited vision about how these might be used. The synopsis of the proposed asphalt mixture specification was only one sentence long.

> *"The asphalt research program will culminate in the preparation of performance-based specifications for asphalt and recommendations for an asphalt-aggregate mixture analysis system using modified or unmodified asphalts."*

In reality, the need for the classic HMA parameters remained. And, today they are part of the Superpave mixture design system.

Midway through the research program, the realization occurred that the engineering properties being identified in the research were sufficiently complicated to be impractical for low traffic volume pavements where the risk of poor performance was low. Ultimately, the engineering properties from the research were impractical to implement. As a result, the vision that engineering properties of HMA would be measured and matched to the demand of the application never came to fruition. The size of the problem was much larger than had been envisioned.

Today the Superpave mix design system is an improved method of volumetric mixture design that falls short of the vision, however brief, presented in the "Brown Book." In part this is because of low priority originally given to mixture design, which was later "added in" to the research program. In addition, this is because the problem of identifying and measuring engineering properties was much more difficult than had been anticipated. Even today (2012), after an additional 19 years of continued research, the industry is just at the point where implementation of a system of specifying and measuring engineering properties related to pavement performance may be actually realized.

Additionally, a greater breadth of expertise was needed. Although statisticians were instrumental in the development of the experiment designs, their talents were not fully employed in the data analysis, likely because of budget constraints and the then unfamiliarity with a statistical approach that is now widely accepted. From the equipment perspective, the absence of mechanical and electrical engineering expertise was evident in problems with the binder direct tension test and mixture indirect tension and shear tests.

Another example of too narrow a breadth of expertise was the lack of computer programming expertise, which left much of the heavy lifting to civil engineers with a "gift" or "passion" for programming to develop the Superpave software. There were two major components to the Superpave software. The core software was designed to evaluate performance test results, extract pertinent asphalt mixture material properties and predict performance. The core software was to interface with shell software that would collect project-specific data, manage input of test data files and display performance predictions. More than any other area, the interface between the shell and the core software was the most unworkable. The shell software was developed by a professional software development company. Development of the core software was added to the activities of a graduate student. Documentation of the core software code, not surprisingly, was very limited. Considerable resources were dedicated to development of the core and shell software which today have been discarded. Understanding of the size of the computer programming requirement and using professional software developers could have yielded a workable software program. How much the lack of workable software caused the performance-based tests to be judged too complex for implementations is open to speculation.

6.5 BASE DECISIONS ON OBJECTIVE DATA

In any large research program there will be differences in technical opinion. On the one hand, it is important to encourage different thought processes which are crucial to the discovery of new ideas. At the same time, the research program must coordinate numerous competing fields of study that, if left uncoordinated, lead only to new ideas and not to a final product.

A great challenge of research programs that are required to develop an implementable product is to determine the balance between allowing additional effort for the study of ideas and the decision to shelve an idea and move on. The challenge for the technical director of the research effort is to ensure that the researchers do not feel unfairly treated and withdraw emotionally from supporting the goal of the research program. If left unchecked, such feelings can at the very least create a negative drag on the program and could cause its disintegration.

Two examples arise from the research program. One worked out well; the other did not.

In the area of low-temperature cracking the A-003A team investigated the use of the Thermal Stress-Restrained Tensile Test (TSRST) for the measurement of low-temperature cracking susceptibility. The A-005 team was concerned that the test was a torture test and would not yield engineering properties that could be used to predict cracking. Instead, the A-005 investigator wanted to use a creep test measured with indirect tensile creep plus tensile strength. To resolve this difference, the A-003A and A-005 investigators were asked to collaboratively design an experiment to evaluate mixtures with different low-temperature cracking potentials and to each test them using their respective approaches. A week later an experimental plan was developed and several weeks later the results were presented.

When the results were presented, the A-003A team compared the cracking temperature for each mixture with the expected performance and demonstrated that the TSRST ranked the mixtures according to expected performance. The A-005A team presented the results of the tensile creep and tensile strength tests and predicted the performance for a specific geographic region. The results concurred with the expected performance. Further, the investigators predicted the cracking temperatures of the mixtures in the TSRST test, which had a much higher cooling rate than that which occurred in nature. The predicted cracking temperature for each mix matched well with the measured cracking temperature.

On the basis of these experimental results, the decision was made to use indirect tensile creep and strength in the Superpave mixture specification. The TSRST was designated as a research tool to validate the asphalt binder specification. Once this decision was made, work progressed on using indirect tensile testing for low-temperature cracking.

The success of this approach for low-temperature cracking should have encouraged a similar approach for rutting and fatigue cracking. However, because each of the respective researchers had a long history with and was deeply committed to their respective approaches, such a cooperative experiment was never developed. Thus, objective, empirical evidence was not available with which to reach a clear-cut decision. A decision was postponed while considerable capital resources and emotional capital were expended. Finally, under the pressure of deadlines, a decision was made that proved less than satisfactory—adoption of the difficult-to-implement performance tests for rutting and fatigue cracking based on the Superpave Shear Test device.

6.6 PROVIDE STRONG TECHNICAL LEADERSHIP

The research program must have strong technical leadership as well as good administrative leadership. Technical competence enhances the legitimacy of the leader in the eyes of the researchers, especially when unfavorable decisions must be made. The technical leader can and should make use of expert panels to review research and recommend action. But the leader should have sufficient technical ability to justify decisions that are made.

One challenge a technical leader faces is trying to make judgment of ideas that are in the process of being "discovered" or developed. Sometimes there is not an obvious answer as to whether an idea should be pursued further or set aside. The pressures of time and budget ultimately force decisions to be made, sometimes to the dissatisfaction of the researchers. A strong leader with competent technical skills enhances the chance of success.

The SHRP Overview and Integration Report (commonly known as the Brown Book) that laid out objectives and plans for the research program recognized the leadership challenge in stating that "The technical and administrative management of SHRP will be a complex endeavor requiring the most effective management and communication tools available." These words proved to be very true. Some of the technical controversies which occurred among the team members, such as compaction method, tests and models, pushed the technical leader and the administrative leader to the limit of their abilities. Many of the issues were successfully decided. Others were not.

6.7 ANTICIPATE THE POLITICS OF IDEAS

One of the challenges for a research project is to determine which ideas to advance and which to leave behind. The leaders must reconcile the personalities of the lead researchers.

Generally, the lead researchers in the Asphalt Research Program had years and decades of research experience. Ideas developed during that time became the basis of moving forward. Typically such research had been done in distinct geographic or academic environments. And generally the researchers felt constrained by the lack of resources (money) to develop their ideas further. The SHRP Asphalt Research Program was viewed as a vehicle to at last provide adequate funding to allow development that was national in scope to occur. As a result, competition for the research contracts was intense among the well known researchers of the day.

It has often been stated that contract A-003A, which was tasked with developing asphalt mixture tests to measure engineering properties, and contract A-005, which was tasked with developing material response and performance models, were awarded in the wrong order as is obvious from Figure 42. Indeed, if the goal of the asphalt mixture research program was to select engineering properties to predict mixture performance, then the first order of business should have been to select the properties and the models for material behavior and mixture performance. Then, the contract to develop tests would be constrained to finding appropriate tests to measure the identified properties.

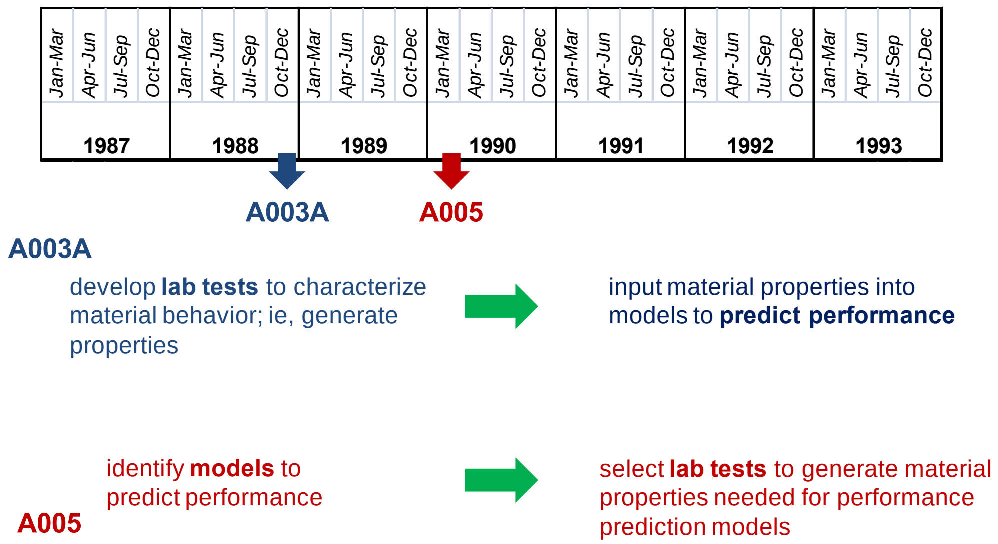


Figure 42 Sequencing of A003A and A005 Projects

Instead, because the testing contract led and the modeling contract followed, the stage was inevitably set for conflict. As part of testing a mixture there was a need for material response models. So independent of the modeling contract, material property models were selected.

A short discussion of models is appropriate for understanding the situation. In simplistic terms a material property model would predict the stress and strain response for a material. As part of this model, a basic type of behavior must be encoded.

The behavior of hot-mix asphalt is complex. Hot-mix asphalt is a composite material of compacted granules of aggregate glued together by asphalt binder. The response of systems composed of compacted particles is by itself complex. In addition the properties of the added asphalt binder change with temperature and time of loading. The resulting hot-mix asphalt has numerous types of behavior depending on temperature, time of loading and age. As a result, hot-mix asphalt can react as a linear elastic material, a non-linear elastic material, a visco-elastic material, a visco-plastic material and a plastic material. For any given combination of temperature and time of loading, the HMA can react with one behavior or a combination of the above behaviors. Material models that capture all of this behavior will be complex indeed.

From the material response model, stresses and strains can be predicted as load and temperature change. After determining the stress and strain response, performance models are used to predict behavior of the asphalt mix. How much unrecoverable strain (rutting) will occur? Will it crack from fatigue behavior or from low temperature?

During the SHRP Asphalt Research program, the modeling contract selected material property models and performance models that did not use the properties coming from the test development contract. And, the modeling contract was developing tests to measure their properties because the tests from the other contract did not work as well for those properties.

Why did this occur? Each group had different ideas about how best to model the behavior of HMA. Each approach made sense, but the two approaches were different. Attempts to understand the advantages of each and to compare the differences led to a defensive posture with each camp defending their ideas.

Finally, when reconciliation seemed impossible, the decision had to be made. Time and budget no longer allowed the two independent approaches to continue. The A-003A contract was responsible for developing tests. The A-005 contract was responsible for the material response and performance models. And so, the tests developed by A-003A would be used. The A-005 contract would extract material properties from these tests and use them in the models. The result was a less than optimal approach that ended up being non-implementable. The research leader of each contract had defended their ideas and each felt their approach had been discriminated against in the final decision.

Also, each leader still believes that their approach is the better one. Today, 19 years after the end of SHRP, neither approach has penetrated the market. Most asphalt industry engineers (both contractor and state DOT) are unaware of the findings of either researcher and almost none have used them.

During the time of trying to reconcile the two approaches, a third researcher was used as an expert to understand if the work of the two could be used in a single approach. The net effect of this effort was that during additional NCHRP work to complete the models and performance prediction part of Superpave the third researcher rejected the approach of either of the two SHRP contractors and promoted his own ideas for testing and modeling. Hence the work of the A-003A and A-005 contracts remains largely unused to this day.

In the view of the third researcher, the approach he had been developing since the 1960s was the best approach for the prediction of rutting and fatigue cracking. When the third researcher performed post-SHRP research on the "Simple Performance Test," the SHRP methods were evaluated and rejected in favor of the researcher's own approach.

So, what does all this mean? All these researchers were convinced that their approach was the best approach. The main lesson to be learned from this is that all researchers tend to be vested in their own ideas and it is difficult, perhaps impossible, for them to be objective regarding other possibilities. As a result, special care and attention should be given to fostering cooperative research and subduing defensiveness to challenges of established concepts.

6.8 DEVELOP A TEAM PHILOSOPHY

Beyond the sheer technical difficulties confronting the SHRP researchers, there was also the challenge of developing a team philosophy that mediates the disparate personalities of the researchers involved.

While different thinking can be the source of new discoveries, if not managed well, differences in philosophy can be destructive to the overall team. Just as in sport or business, strong teams can produce great accomplishments. Teams that break down, that show a lack of respect among the team members, can be very ineffectual.

One of the key challenges for the technical and administrative directors of a large research program is to develop and nurture a team mentality. During the asphalt research program there were examples of both good and bad team behavior.

From the beginning of the research program, research teams from each of the contracts assembled for a multiday meeting several times a year. These were large meetings attended by 30 to 50 people. Each research team would present plans for experiments and through discussion would receive feedback from other investigators. Therefore the other investigators acted as a sounding board. During and after the experiments, results would be presented to the group. Discussion would help with evaluation of the test results as well as determining if those experiments impacted experiments others were running.

On one such occasion an experiment to investigate the mechanism of moisture damage was being discussed. Asphalt binder molecules were known to adhere only to specific sites on the aggregate surface that had suitable chemistry. The hypothesis was that aggregates exhibiting stripping behavior had a lower density of active sites than aggregates known to be resistant to stripping.

But the experimental results were puzzling. The granite aggregate was shown to have approximately the same number of active sites as the limestone aggregate, yet the granite was known to be a stripping aggregate. When water was added to the system, the asphalt molecules were detached from the granite but not from the limestone. One of the other investigators started writing equations on an overhead transparency and asked to share his thoughts with the group. Gibbs Free Energy (essentially the energy given off during adsorption of a molecule to a surface) just might explain the results. At the next meeting the investigator showed results to confirm that energy of adsorption did indeed explain the phenomena of stripping.

This is an example of team philosophy. Despite working for different organizations and being involved with different research contracts, the exchange of ideas helped solve a problem. These two individuals worked together because there was no competition between them. There are many other examples of team work to solve a problem within the asphalt research program.

Strong differences in philosophy, however, can lead to a non-supportive environment. For example, one researcher believed the team was being asked to push the bounds of knowledge and that the search for truth was a pure and admirable goal. This belief fostered the view that the researchers should tell state DOTs and industry what is required to get the truth. In fact, the leaders of the research program considered implementation issues identified by industry and agencies and modified research recommendations for implementation based not only on the findings of the research but also on political necessities. The leaders saw this as being pragmatic and increasing the chances of successful implementation. The researchers saw this as a sign of weakness. Ultimately, this generated a lack of respect between the individuals and created a disruptive force on the team.

A team’s performance is enhanced when its members respect one another and work together. This does not connote a “Pollyanna” atmosphere where only sweetness and smiles are present. It does mean that team members can disagree but still respect each other because the team is more important than the individuals of which it is composed.

6.9 EXPECT RESEARCHERS TO BE SOLELY DEDICATED TO THE RESEARCH EFFORT

Usually researchers are involved in a multiplicity of activities. A university professor may have multiple research projects, teach classes and be involved in university administration. A consultant may have multiple customers and performing research for a particular client may be only one of the activities with which they will be involved.

In normal research, multi-tasking is routine. The main difference between the SHRP research and much other research that had gone before it was the imposition of a deadline and the demand for implementable products. Many of the researchers devoted large percentages of their time to the SHRP research. Several worked solely on SHRP research. For them, the asphalt research program became a sole focus.

Others who devoted a lower percentage of time found the SHRP research competing with other demands. As a result, their view was not solely focused on the asphalt research program. For a focused research project such as SHRP there are benefits to a sole focus.

The technical leader of the A-001 contract would compare the mission of the SHRP Asphalt Research Program to that of the development of the atomic bomb. Technically, it was not known if the mission to develop performance-based properties for asphalt binder and asphalt mixture could be accomplished. It was not clear whether the technology existed to accomplish this mission or if the technology could be developed. As discussed earlier, the lack of performance-based properties and performance prediction for Superpave mixtures is partially based on the inability to completely conquer the technical challenges. Tom Kennedy hypothesized that if the researchers were co-located to a location devoid of outside interferences that the possibility for success would have increased. Given the size of the Asphalt Research Program and the high profile in the technical community, it may have been possible to require that researchers be given a leave of absence from their regular position for the duration of the SHRP research.

The lesson to be learned is that if the problem is sufficiently large, and the outcome uncertain, it may be advantageous to dedicate sole effort of the participants to the research effort.

6.10 BUILD A COOPERATIVE COMMUNITY

With a new technology as far-reaching as Superpave, it is important to build a community that shares information to help everyone progress up the learning curve. Some of the most memorable legacies of Superpave stem from building these communities or peer groups.

The Expert Task Groups are the best example of this. The ETGs have become so important and so influential that their recommendations are carefully considered by AASHTO as changes are made in the standards and guidelines. The ETG concept has now been expanded beyond the Binder and Mix ETGs to also include groups looking into Models, Recycling and Warm Mix Asphalt (though that is called a technical working group (TWG), its aim is the same). The WMA TWG in particular has been very successful in obtaining research funding in support of its highest rated research needs. It is anticipated that ETGs and TWGs will continue to be used in the future to oversee and coordinate efforts in a variety of fields.

The User-Producer Groups have also been quite successful. The UPGs are among a very few venues where agencies and industry can gather and share information on a regional basis. This provides a way to transmit a common message to a large group of people and get feedback from a variety of perspectives. The UPGs have evolved, tailoring their activities and programs to meet the needs of their own regions. Recent economic problems and severely reduced opportunities for agency personnel to travel have hampered the ability of some states to fully participate in the UPGs, but it is hoped that this will be a short-lived barrier. As long as the UPGs can put together compelling programs and share worthwhile information, it is anticipated that they will continue to function as a beneficial communication tool.

The Lead State Team was another example of a cooperative community. Although it had a limited lifespan, it is a good model to consider for future implementation efforts. Not every state or every contractor needed assistance from the Lead State Team, but for those who did need a little advice, getting it from their peers (state to state, contractor to contractor) was very effective. The all-too prevalent distrust between agencies and industry can be mitigated by such peer exchange.

The early days of the Superpave Centers also fostered this cooperative exchange. Frequent meetings between the Centers definitely helped to coordinate research, training and shakedown testing of the new equipment. Lasting friendships and cooperation were established between the Centers and, in most cases, between the Centers and their clients.

6.11 FIND A CHAMPION FOR THE RESEARCH RESULTS

As indicated in the report, the main short-coming of the SHRP Asphalt Program was the non-implementation of mixture performance prediction models. Various reasons can be offered for an explanation, including the facts that the task was more difficult than anticipated; inadequate resources were directed to the task, especially the computer software, and others.

At the end of the SHRP research effort the products included performance-based mixture tests for rutting, fatigue cracking and low-temperature cracking. The products also included performance prediction models. It would seem the research project goals were met, but none of these products ever saw implementation. Why? For lack of a champion.

The rutting and fatigue cracking prediction models were a composite of performance tests developed by the A-003A team that were considered by the A-005 team to be less than desirable. The A-005 team had been directed to extract material properties from the A-003A tests and use them in the performance prediction models. This situation occurred as a compromise since both the A-003A and A-005 teams each developed a set of performance-based tests and performance prediction models. Each team had hoped to convince the A-001 technical coordination team that their set of tests plus prediction models was superior and should be adopted.

An outside expert from the University of Maryland helped mediate the technical debates and provided input on what was possible to do.

So at the end of SHRP, as implementation began, a contract for continued development of the models was won by the University of Maryland. Consider the situation:

- It was clear to the AASHTO Lead States group and FHWA that the performance models were not ready for implementation.

- The A-003A researchers agreed with the tests included in the system but disagreed with the performance prediction models and their use in a mix design system. In fact, they continued independent development of their system for several years following SHRP.
- The A-005 researchers disagreed with the tests being used to measure performance properties and so continued to develop their tests and the performance prediction models.
- The A-001 principal investigator had serious health issues and became a non-participant.
- The FHWA was committed to implement SHRP and set up a pooled fund for states to purchase equipment. When problems with the performance prediction became known they put a hold on that equipment and supported continued development with a large research contract.
- NCHRP funded a project to develop a simplified version of the Shear Tester to reduce the equipment cost and complexity, major stumbling blocks to implementation. Although successful, the principal investigator of the project had no desire to push for implementation.
- The FHWA contract to continue development of the SHRP performance prediction models was won by the University of Maryland. This researcher was strongly invested in dynamic modulus research since the 1960s. He strongly viewed the shear tester as being technically flawed. He became involved in the AASHTO pavement design project (now known as DARWin ME) and used dynamic modulus as the basis for asphalt mixture properties and performance prediction.
- Ultimately, he pushed for adoption of the dynamic modulus test in lieu of the A-003A or A-005 tests. He also developed his own modeling and performance prediction which became part of the Mechanistic-Empirical Design Guide, now DARWin ME.
- A stand-alone performance evaluation for mix designs was not developed.
- Only now (2012), 19 years after the end of SHRP, are states beginning to implement a performance-based test (the Asphalt Mix Performance Test) and performance prediction models (in the MEPDG/DARWin ME), though both differ from those envisioned during SHRP. In the interim, some states have adopted various wheel track testers and other empirical tests. Others continue to design using only the classic volumetric properties.

What's the lesson in this? There was not a ready champion for adoption of performance-based tests for asphalt mix. As a result, nothing was implemented.

6.12 RECOGNIZE SIZE OF THE IMPLEMENTATION EFFORT

As implementation of Superpave progressed, it became apparent that the scale of the implementation effort would far exceed that of the research phase itself in terms of time, resources and funding. While the SHRP research period lasted for a nominal five years, the implementation efforts have been going on for 18 years and counting. Thousands of pieces of equipment have been purchased for laboratories across the country, and thousands of people have been trained to perform the testing, analyze the results and employ the new technologies. The costs associated with those equipment purchases and training efforts are virtually impossible to quantify. Follow-up research conducted through the NCHRP program alone, however, amounts to over $16 million. Research funded by individual states, industry and other groups likely exceeds that amount.

It is safe to say that although many recognized that significant investments would be required to implement the Superpave technology, the total magnitude of that investment was not initially anticipated. Future implementers of large-scale research efforts should be aware of the magnitude of the task ahead of them.

As noted before, in some areas, the research under SHRP was not complete when time ran out, leaving a significant amount of follow-up work to be undertaken. Even if the research had been completed to the point of having purchase specifications for equipment, validated testing and analysis methods, etc., the effort required to implement a new system on the scale of Superpave is enormous. The benefits are equally great, however, so the magnitude of the effort should not be a deterrent. Knowing the size of the task ahead, however, should allow for more realistic time frames and budgets to be developed. It should provide an opportunity to put in place measures to ensure that adequate training is available and that resources can be made available when needed. These needs should be anticipated and not underestimated.

6.13 CULTIVATE CONTINUED SUPPORT FOR PROGRAMS (BOTH FINANCIAL AND INTELLECTUAL)

Along with recognizing the size of the research and implementation efforts comes the need to cultivate continued support for the programs. The budgetary needs perhaps come first to mind, but there is also a need to support the program intellectually or through the personnel involved.

As a long-term research program or implementation effort progresses, the personnel involved will grow and change. It is essential to bring new people "into the fold" and keep the interest level high. The Long-Term Pavement Performance program is one example of this effort. Most of the original state champions (state coordinators) for the program have advanced in their careers or even retired. People occupying those positions now are frequently not familiar with LTPP, its history, its goals, its needs and its benefits. FHWA and the regional LTPP contractors have had to make outreach efforts to inform the new personnel. This is especially true, of course, for the chief executive officers (commissioners, chairmen, etc.), who tend to change about every two years or so.

Another aspect of the continued support is planning ahead to ensure that the resources needed for follow-up research and validation efforts are available. The Materials Reference Library has proven to be an excellent resource that allows the work under SHRP to be expanded through numerous projects undertaken since SHRP. Future large-scale materials related projects would be well served by following this model and providing for accessibility of material samples. Archeologists sometimes choose to document the location of an archeological site but leave it in place, undisturbed, for future archeologists to investigate with improved technologies. Engineers and other researchers could learn from their example and preserve samples that can be tested or analyzed in the future.

All projects would benefit from ensuring the accessibility of the raw data that was collected during the research. Data maintenance and management is an ongoing commitment, not a onetime effort. As computer technology changes, data may need to be transferred or translated to new formats. Data from the AASHO Road Test, stored at the time on magnetic tapes, has been lost. The LTPP program is currently grappling with data storage and accessibility issues and must plan for the safe storage of backups to preserve the otherwise irreplaceable database amassed over 20 years.

So, there is a need to build grassroots support for the program and continue to promote the program. Data should be maintained in a format accessible by future researchers who may have insights into new methods to analyze the data; samples should be preserved, if possible, for future improved testing and evaluation. This is not a task that can ever be completed and checked off the list.

6.14 INVOLVE RESEARCHERS IN IMPLEMENTATION EFFORT

In applied research, the researcher should articulate a clear vision as to how the results can be effectively (technically and economically) used by the client. As part of this vision, it is imperative that the research consider the background, expertise and operating environment of the end user.

This is an area that was not used fully. During the research period early implementation fell most strongly on the A-001 contract team. Other researchers were involved to a limited extent. It is likely that increased involvement would have fostered a greater sense of team.

6.15 COMMUNICATE WITH THE INTENDED AUDIENCE

Communication with the intended audience – the end users – is vitally important to keep them abreast of progress, to help them prepare for what is coming, and to dispel rumors. This communication should be done before the research starts to outline plans and objectives, during the research to keep the program on the radar screen, and after the research during implementation. It is also important to clearly communicate the status of the research. People need to know that findings are preliminary or tentative and that changes are likely, so that they do not expend resources preparing to implement something that changes dramatically later.

6.16 GET THE TECHNOLOGY OUT TO THE AUDIENCE

Past experience in some endeavors has shown that rolling a product out before it is ready can be its death knell. If users try something and it does not work as promised, they are unlikely to try again. On the other hand, letting users know what is coming can help them plan ahead. Users can help in the refinement of a product by giving feedback on potential problems or considerations. The important thing is to make sure the users know they are looking at a draft or prototype, not a finished product.

In the SHRP Asphalt Research program, the use of the strawman specifications was very useful. Potential users could begin to see what they would be dealing with in the future. Such specifications also served to focus the researchers on the ultimate product they were expected to produce and drive home the need for practical, workable specifications.

The provisional standards were also very successful. They showed people that products were coming, but their provisional status made it clear that future refinements could be expected. Users could decide when to dip their toe in the water and when to dive in head first. It is anticipated that AASHTO will continue using the provisional standards for years to come.

Other successful examples of getting the technology out to the audience include the loaned binder equipment and the pooled-fund equipment buy. FHWA has continued to offer to lend some equipment to agencies for trial when feasible; examples include outflow meters, safety edge molds, etc. The pooled-fund equipment buy was highly successful and is a model that is being followed in other applications, most notably the AMPT procurement.

6.17 BENCHMARK

Benchmarking is an excellent tool for charting and encouraging progress. The Lead State Team implementation surveys benchmarked where states and industry were in regards to Superpave implementation. The annual surveys showed how the technology was growing in acceptance. There are numerous examples where an agency executive would see the survey results and ask the technical staff, "Why are we lagging behind our neighbors? Why aren't we taking advantage of this new technology?"

6.18 CONCLUDING OBSERVATIONS

The Strategic Highway Research Program was an unprecedented, large-scale highway research effort. The asphalt research effort under SHRP led to substantial changes in the entire asphalt industry in the United States, Canada and overseas.

The SHRP Asphalt Research Program resulted in the Superpave mix design system, Performance-Graded binder specification, and many supporting new test protocols and equipment. The implementation of the products of this research program stimulated change in every facet of the asphalt industry. Superpave pavements have been shown to perform better, in general, than previous mixes. Overall, Superpave is recognized as one of the major success stories of SHRP.

Not all of the technical efforts under the Asphalt Research Program were entirely successful, however. The planned performance prediction models are still being sought through other research efforts. Moisture damage still occurs in pavements, and there is no widely accepted test method to prevent its occurrence.

From a non-technical viewpoint, there were ancillary benefits of the SHRP Program. Many young engineers and researchers were brought into the research and/or implementation efforts at an early stage and have gone on to have illustrious careers. More established researchers were able to make a mark and solidify their reputations. Others were scarred by the clash of egos and disputes that arose.

A review of the research and implementation efforts from both a technical and a programmatic perspective documents the evolution of the Superpave system. In addition, the review revealed a number of lessons learned. These lessons may benefit future large-scale research programs.

- Make decisions transparent and firm.
- Document the decisions made.
- Ensure strong technical leadership with management skills
- Have a clear vision of the scope, size and complexity of the problem.

- Recognize the "politics of ideas" and that researchers will defend their positions.
- Develop an atmosphere fostering teamwork and cooperation rather than competition.
- Try to ensure researchers have the time and resources to be dedicated to the effort.
- Build a cooperative community to help others adopt the new technology.
- Recognize the size of the implementation effort – it may be even greater than the size of the research endeavor.
- Ensure continued support for the implementation process.
- Involve researchers in the implementation effort, and users in the research effort.
- Communicate clearly with the eventual users of the research results– give them an idea of what is coming but make it clear what is preliminary and what is ready to implement.
- Get the technology out to the users – strawman specifications, first article procurements and pooled-fund equipment buys are very effective strategies to get people to try new technologies and get feedback to refine the products.
- Benchmark the status before, during and after implementation to document the success – or lack thereof – of the research and implementation effort.