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OFFICE OF PLANNING & RESEARCH

RESEARCH AND DEVELOPMENT PLAN FOR I-99 ADVANCED TRANSPORTATION TECHNOLOGY TEST BED

University-Based Research, Education and Technology Transfer Program
AGREEMENT NO. 359704, WORK ORDER 33

FINAL REPORT

OCTOBER 30, 1999

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The purpose of this research project was the development of a research and development plan for a proposed advanced transportation technology test bed on the I-99 highway. The concept of the test bed was unique in many ways:
1) It sought to implement continuous, long-term testing on a broad scale on an operational interstate facility;
2) It would require close cooperation between the University and the PennDOT local district;
3) It would recognize and be responsive to private-sector concerns and issues; and
4) It would be responsive to problems throughout the Commonwealth, not just in the I-99 region.

The areas of exploration in the work order were traffic and ITS, geotechnical engineering, structural engineering, materials and construction, pavement performance, and hydrology and hydraulics. Penn State researchers worked cooperatively with PennDOT District 2 to develop an invitation list, which included other PennDOT districts, PennDOT headquarters, the Federal Highway Administration (FHWA), consultants and contractors engaged in I-99 work, and local transportation agency representatives from the Centre County area. Attended by 112 professionals, the conference was organized into a series of structured interactions aimed at identifying technical issues of importance for PennDOT and other highway agencies that can be addressed through test bed experimentation, and reaching consensus on the research approaches needed to attack the problems, again focusing on those feasible within the test bed.

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FINAL REPORT

Prepared for

Commonwealth of Pennsylvania
Department of Transportation
Office of Planning & Research

By

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Background

The Research and Development Plan for the I-99 Advanced Transportation Technology Test Bed has evolved from a unique partnership between the Pennsylvania Department of Transportation (PennDOT) District 2 and Penn State faculty. For a period in excess of a year, at times prior to a formal work order, District engineers and Penn State faculty met to discuss issues and problems that needed to be addressed during the construction of the highway. These initial discussions, conducted in fall 1998, led to a common understanding that many of the technical challenges facing the local design team could be addressed by advanced technology applications. Further, there was a belief that the issues identified and the solutions proposed would be relevant to the Commonwealth as a whole. In the context of this broad cooperation and partnership, a work order was prepared for Penn State to develop a research and development plan for I-99.

The purpose of this research project was the development of a research and development plan for a proposed advanced transportation technology test bed on the I-99 highway. The concept of the test bed was unique in many ways:

1. It sought to implement continuous, long-term testing on a broad scale on an operational interstate facility;
2. Successful implementation would require close cooperation between the University and the PennDOT local district;
3. Successful planning should recognize and be responsive to private-sector concerns and issues; and
4. The test bed would have to be responsive to problems throughout the Commonwealth, not just in the I-99 region.

The areas of exploration in the work order were:

- Traffic and ITS,
- Geotechnical engineering,
- Structural engineering,
- Materials and construction,
- Pavement performance, and
- Hydrology and hydraulics.

To stimulate discussion in each of these six areas, white papers were prepared by Penn State faculty. These white papers were based upon the issues identified in prior meetings with PennDOT, the knowledge of the researchers, and their perception of research opportunities in the areas. These white papers are contained in Appendix A.

Penn State researchers worked cooperatively with PennDOT District 2 to develop an invitation list, which included other PennDOT districts, PennDOT headquarters, the Federal Highway Administration (FHWA), consultants and contractors engaged in I-99 work, and local transportation agency representatives from the Centre County area. Attended by 112 professionals, the conference was organized into a series of structured interactions aimed at:

1. Identifying technical issues of importance for PennDOT and other highway agencies that are addressable through test bed experimentation; and
2. Reaching consensus on the research approaches needed to attack the problems, again focusing on those feasible within the test bed.

The conference was professionally facilitated to encourage open discussion and to solicit broad input on technical issues. As a result of this approach, a large number of technical issues were identified and discussed in each of the workshop sessions. As the day proceeded, many alternative research approaches were also considered. The total number of issues identified exceeded 115; feasible approaches exceeded 36. Details of the deliberations in each workshop session are contained in Appendices B and C.

The summarizing of over 115 technical issues and 36 research approaches consumed significant time and staff resources after the conference. As expected, many of the technical issues identified in the sessions overlapped; for example, issues identified in construction and materials were also found to be important in pavement performance. While the overlap was expected, the effort necessary to combine and correlate the issues was underestimated. Penn State faculty met several times after the conference to combine the technical issues and research approaches to a manageable number and to add cost estimates to the research approaches.

Summary of Technical Issues

In order to make meaningful recommendations to PennDOT concerning technical issues, they were divided into four application areas: bridges, pavements, hydrosystems, and traffic and ITS. Penn State faculty reviewed the records of the meetings and consolidated a very comprehensive set of recommendations into a smaller, more coordinated set. Problem statements that were similar in scope and importance, but recommended in more than one workshop, were consolidated to eliminate duplication. Only the top-rated issues are discussed in this report.

One of the strongest findings of the conference was the consistency in the perceptions of the major technical issues confronting PennDOT and highway transportation. The summary in this section represents a strong consensus concerning issues that need to be addressed to advance PennDOT into the next millenium. The highest-priority technical issues included:

- **Movement and stresses in skewed and curved girder bridges** - Improvements are needed in design methodologies for skewed and curved girder bridges due to the difficulty of accurately predict movement and stresses in the structure during construction and service. The Curved Steel Bridge Research Project (CSBRP), initiated by FHWA, examines curved steel bridge behavior in the laboratory. Penn State faculty have been intimately involved in this testing for the past 2 years and expect to be in the future. The I-99 Advanced Transportation Technology Test Bed offers the unique opportunity to instrument and study skewed and curved composite bridges during actual construction and service life. This is an important enhancement of FHWA laboratory studies that will lead to an improved understanding of behavior and provide a basis for validating and improving design procedures. This project was the highest- rated problem emerging from the structural meetings at the conference.

- **Inability to prevent deck cracking** - Each year, transportation agencies across the United States invest tens of millions of dollars in concrete bridge deck repair, replacement, and rehabilitation. These projects not only consume resources, but cause significant delays for the motoring public on highways and roads. The I-99 project provides an opportunity to study the effects of numerous variables influencing deck cracking, including mix design; placement sequence; curing; reinforcement details; girder stiffness; length and spacing; traffic volume; loading; and impact. Recent developments in the technology of high-performance concrete could lead to significant improvements in concrete deck performance. The significant number of bridges planned for construction in this project provides an excellent opportunity to perform controlled studies of the variables involved. This problem was the fourth-rated issue in the structures sessions but was the top-rated issue in the materials and construction sessions.

- **Design of integral abutment bridges** - Integral abutment bridges provide a solution to the problems associated with expansion joints in bridges. A number of design approaches have been proposed; however, field data are needed to validate proposed methods and to provide needed information on performance of integral abutment bridges, including prediction of movement and long-duration stresses. The design issues include orientation of piles and design assumptions, performance of approach slabs, and effects of soil pressure on back walls and wing walls. Skew effects are also important for integral abutment bridges. The I-99 test bed offers a unique opportunity to examine these deficiencies and the behavior of integral abutment systems as a whole, both during and after construction. This issue was rated third in importance within the structures meeting but was part of the highest-rated project in geotechnical engineering at the I-99 conference.

- **Construction of bridges using new seismic designs** - Recent changes in requirements for seismic designs have led to problems due to congestion of reinforcement in bridge piers. Many of the required details are based on experience with earthquakes in California. The appropriateness of these requirements for bridges constructed in the Mid-Atlantic region needs to be closely examined. The I-99 project provides an opportunity to document problems experienced during construction of piers with these seismic details in conjunction with a study to establish seismic design requirements for Pennsylvania. This was the second-highest rated issue during the structures sessions at the I-99 conference.

- **Geotechnical problems associated with bridges** - A number of geotechnical issues associated with bridge construction are amenable to study in the I-99 project. These include methods for site investigation and characterization, approaches and foundations for bridges, lateral loads on structures, use of alternative abutment fill materials, pile design values, and development of appropriate bearing-capacity estimates for rock. These issues received the top-priority ranking in importance during the geotechnical meeting at the I-99 conference.

- **Design and performance of pavement subgrades** - Issues concerning pavement performance raised during the conference included joint movement, seasonal behavior of subgrades, subbase drainage efficiency, and crack development. Attendees agreed that these issues are critical to the success of a pavement design and that critical questions exist about current design practices. There is a need to conduct *long-term* monitoring of rigid pavements to learn more about the four issues referenced. Information collected through a systematic monitoring program would provide a valuable database for improvements in design and construction of pavement. The I-99 project provides unique opportunities for monitoring. Attendees supported the development of a detailed instrumentation plan that could be used for selection and installation of sensors. These topics were the top-rated set of research studies recommended from the rigid pavement group.

- **Use of recycled materials** - Opportunities for use of recycled materials should be evaluated. There are significant opportunities to test and evaluate a range of products in a number of different engineering applications. PennDOT personnel at the materials sessions were particularly supportive of this issue. Pennsylvania DEP is also strongly supportive of initiatives in this area. While not the highest-rated issue in any singular session, this topic was mentioned at several and has strong support in the Commonwealth.

- **Documentation of construction practices** - There is a need to carefully document and evaluate construction practices, materials (including variability), and effectiveness of inspection to evaluate their effects on pavement performance. Innovative bidding and contract procedures as well as bonus/penalty criteria could be considered. This topic was highly rated at the rigid pavement workshop; it is ideally suited to graduate student activities and interests and may even extend to undergraduate support as well.

- **Improved modeling of surface and subsurface water quantity and quality** - The I-99 corridor is being subjected to unprecedented levels of monitoring for water quality and quantity. While there are unique aspects of the watershed in the region that argue for this treatment, a concern was expressed at the I-99 conference that monitoring at this level may reasonably become the norm. The cost associated with this monitoring, over a ten-year period, is several millions of dollars. There is a need and an opportunity to calibrate accurate project-scale models of water quality and quantity, which can obviate the need for the monitoring, or reduce its duration. The ultimate objective would be to develop a predictive water quantity and quality model that can reduce the amount of monitoring that is required by federal and state agencies. This issue received the highest priority rating in the hydrosystems workshop at the I-99 conference.

- **Evaluation of erosion and sediment controls** - Approved erosion and sediment controls should be evaluated to determine best management practices (BMPs). This would include review of current literature, current BMPs and Pennsylvania methods to evaluate practices; monitoring BMPs in place; and evaluating field changes and responses to determine why they are done and their relative success.

- **Evaluation of stream restoration** - In the area of stream restoration, it is suggested that a case study on Laurel-Oliver Run Complex, including the review and design procedures of current restoration methodologies, be developed. Regional curves could be developed. Sediment and transport needs to be monitored to assess the impact of the stream restoration practices at hydraulic structures such as culverts or bridges.

- **Evaluation of man-made wetlands** - The I-99 project provides an opportunity to review the objectives, methods, and designs for creating, enhancing, and preserving wetlands. Criteria and methods for evaluation of wetland design and objectives would be determined.

- **Improved winter maintenance and hazardous materials response** – Winter maintenance needs include the development and testing of routing and scheduling algorithms for snow removal vehicles, and automated guidance for maintenance vehicles. Weather and roadway condition monitoring systems would be used to provide information to PennDOT on the locations needing surface treatment. Vehicles would be dynamically deployed to areas of greatest need, enhancing the quality of travel. There is also a need to provide timely response to incidents and emergencies including response to hazardous material spills. Conference attendees recognize that these spills pose a significant risk in remote rural areas. There is a need to have better signing and other infrastructure to allow timely communication to drivers on the road.

- **Smart highway illumination and signing** - Highway signs convey largely static information that does not change with conditions or adapt in real time to enhance driver visibility. There is a need to improve highway signing to enhance safety performance and reduce the occurrence of crashes in adverse weather and visibility conditions.

- **Traffic management center** - A central location is required for receipt and processing of incident information, along with video surveillance cameras and monitoring of weather and roadway conditions. This traffic management center would support all the projects listed in this section and allow ready access and processing of data from the test bed.

Recommended Research Plan

The conference attendees worked from these important technical issues to identify actions or approaches that would respond to the issues. These deliberations took place in each of the six workshop groups. As with the technical issues, a strong consensus emerged, with substantial duplication of action items across the groups. Table 1 matches the high-priority technical issues with a research approach and 5-year cost estimate. Details of the individual research proposals are contained in Chapter 4. The majority of the research proposals involve installation of monitoring equipment in particular facilities during construction with a testing and evaluation period of 1 to 2 years. The 5-year time period was derived from a need to install hardware during the construction of the highway and conduct monitoring and testing for 1 to 2 years subsequent. The total estimated cost of these projects over the 5-year implementation of the test bed is $10.35 million.

Summary

The I-99 Advanced Transportation Technology Test Bed will offer the Pennsylvania Department of Transportation a laboratory to test technologies that will enhance the Department's "Maintenance First" Strategic Plan. The test bed will provide PennDOT with the ability to reduce the life-cycle cost of highway and bridge infrastructure in the state, saving millions of dollars annually. The plan is broad-based, including elements of the planning , design, construction, operation, and maintenance of a highway facility.

This plan for the test bed represents the collective effort of many attendees of the I-99 conference as well as the product of many additional meetings. Implementation of the plan will allow PennDOT to capitalize on the unique opportunity to create a world-class facility on one of the last sections of interstate highway in the United States.

Table 1. Summary of Technical Issues and Research Approaches.

Technical Issue	**Research Approach**	**Cost Over 5 Years thousands of dollars**
Movement and stresses in skewed and curve girder bridges	Conduct analysis and field monitoring of selected bridges through construction to operation.	$1,000
Inability to prevent deck cracking	Implement a range of advanced technologies to improve deck performance; monitor for several years.	$640
Design of integral abutment bridges	Monitor movement and stresses to develop enhanced design methodologies.	$750
Construction of bridges using new seismic designs	Assess economics and constructibility of new seismic standards.	$450
Geotechnical problems associated with bridges	Conduct comprehensive study of subsurface bridge sites prior to, during, and after construction.	$800
Design and performance of pavement subgrades	Monitor existing practice; investigate and evaluate alternative approaches.	$1,650
Use of recycled materials	Use as a test case to monitor and evaluate use of recyclable products in a range of applications.	$440
Documentation of construction practices	Monitor and document construction activities *in situ;* compare to performance.	$350
Modeling surface and subsurface water quantity and quality	Develop and calibrate water quality/quantity model; assess accuracy through monitoring.	$925
Evaluation of erosion and sediment controls	Monitor and evaluate current practices; identify best management practices.	$250
Evaluation of stream restoration	Conduct case study with long-term monitoring of effectiveness.	$500
Evaluation of man-made wetlands	Evaluate man-made wetlands proposed for facility.	$625
Improved winter maintenance and hazardous material response	Develop and test advanced algorithms for winter maintenance and hazardous material spill. applications.	$560
Smart highway illumination and signing	Develop test section for advanced illumination and sign materials testing.	$750
Traffic management center	Design and implement a traffic and infrastructure information center.	$660
Total Funding		$10,350

Chapter 1

Introduction

1.0 Vision of the Test Bed

This project responded to recognition that there is a unique opportunity to link advanced high-speed communications and computer systems to the design, operations, and maintenance of a new Interstate facility. I-99, one of the last remaining links in the nation's interstate highway network, was passing within a few miles of The Pennsylvania State University, one of the nation's premier transportation research institutions. As the construction of I-99 came closer to reality in the region, many started to speak more definitively about pursuing the unique opportunity and developing and refining the *test bed* concept.

The I-99 test bed was conceived as including the capability to test and enhance a range of highway systems. Advanced communications and sensor systems would be linked directly to highway and bridge infrastructure to automatically sense when maintenance and repair were needed. High- performance materials were to be used to greatly extend the useful life of the roadways and bridges. Advanced communication dissemination systems would communicate roadway, weather, and special-event congestion information to the traveling public. One could argue that there are aspects of this vision implemented elsewhere in the United States and, to some degree, in Pennsylvania. While this may be true, it is the integration of the advanced technologies in a single operating site that characterizes the I-99 Advanced Transportation Technology Test Bed as unique.

Broader economic benefits are also viewed as being associated with a concept such as the I-99 test bed. The Penn State Research Park, less than a mile from the proposed test bed, is being developed with Penn State resources to attract top-quality, high-paying firms and jobs to the state. The development of the test bed will demonstrate to these firms the commitment of the Commonwealth to advanced technology and offer firms the opportunity to participate in the testing, training, and educational programs.

PennDOT and Penn State have undertaken a series of collaborative research ventures including the PennDOT/Academic/Industry Materials Partnership, Mid-Atlantic Universities Transportation Center, Transportation Operations and Systems Research and Development Partnership, and most recently, the University-Based Research, Education and Technology Transfer Program. The I-99 test bed was conceived as being supportive of and supported by these existing initiatives.

1.1 Expected Benefits

Traveler safety will improve through the dissemination of pavement condition and roadway and weather information. Periodic and highly frustrating rural congestion will be reduced by the dissemination of information to regional travelers about special events and local attractions, boosting the regional economy. The system will facilitate the expansion of advanced technology systems to address other rural transportation challenges such as rapid response to trauma caused by highway accidents and improved management of hazardous material spills. Overall, customer satisfaction will increase through the improved design, operation, maintenance, and rehabilitation of Pennsylvania's highways.

The I-99 test bed offers PennDOT a laboratory to test technologies to enhance the Department's "Maintenance First" Strategic Plan. The test bed will provide PennDOT with the ability to reduce the life-cycle cost of highway and bridge infrastructure in the state, saving millions of dollars annually. The test bed will support the testing of optimal deicing and snow-removal policies in an actual environment; pavement sensors can tell PennDOT of the road conditions, while computers optimally schedule plows for maximum effectiveness. The test bed will support expanded engineering education opportunities for the Commonwealth. Because the test bed will integrate a range of advanced technologies and communication systems, secondary school students in engineering and high-tech fields will use it to stimulate interest. Undergraduate and graduate engineering and science students will receive hands-on training with the best technologies available. Technicians with PennDOT and those in training programs will be able to access the technology of the test bed for enhanced training experiences.

1.2 Facility as a National Resource

The U.S. Intelligent Transportation Systems (ITS) program has been active for almost ten years. The initial focus of the program was congestion relief and mobility. The focus has shifted somewhat in the latest federal legislation to a concern about deployment and safety. An area that has been receiving scant attention is the integration of infrastructure management and efficiency and ITS.

The deployment of communications hardware and systems, sensors, detectors, and control devices provides an opportunity for the development of an *in situ* laboratory for the study of a range of infrastructure issues. Two facilities have some overlap with this effort: Virginia's Smart Road and Minnesota's Minnroad.

Smart Road is a highway built as a bypass near Blacksburg, Virginia. It is being instrumented with sensors and a range of test equipment intended to generate artificial weather and allow detailed human-factors testing. The program does have a pavement activity, but it is minor in comparison to the infrastructure being installed for human factors testing. The fact that the road is also a bypass, not a section of open interstate, makes Smart Road more of an external laboratory and less an operational test bed.

Minnroad is located in northern Minnesota and focuses exclusively on pavements. It has already been built and does not have the proposed coverage of geotechnical and construction elements that are part of the I-99 test bed. It does also not contain traffic and ITS elements.

1.3 Outline of the Report

The impetus to develop a Test Bed Research and Development Plan was initiated through a series of planning meetings and technical discussions. Chapter 2 describes the steps taken in the development of the R& D plan. It includes a description of the planning of the major research conference, which was the primary input to the plan; a summary of the research issues of importance to highway infrastructure; and the identification of action items in response to these issues. Chapter 3 describes the highest-priority research issues identified in the project conference and other meetings. Chapter 4 summarizes the recommended research plan for the test bed. Appendices are provided to document the complete discussions that occurred during the course of project conferences.

CHAPTER 2

Development of the Test Bed Work Plan

2.0 Overview

The purpose of this research project was the development of a research and development plan for a proposed advanced transportation technology test bed on the I-99 highway. The concept of the test bed was unique in many ways:

1. It sought to implement testing on a broad scale on an operational interstate facility;
2. Successful implementation would require close cooperation between the University and the PennDOT local district;
3. Successful planning should recognize and be responsive to private-sector concerns and issues; and
4. The test bed would have to be responsive to problems throughout the Commonwealth, not just in the I-99 region.

In early discussions with PennDOT concerning the concept, it was clear that consensus building was critical and that grass-roots support for the concept would have to be developed. A series of meetings and communications were established between Penn State researchers and District 2 engineers during the fall of 1998 to develop this grass-roots support, even before initiation of the formal work order. The meetings in District 2 allowed Penn State researchers to better understand local problems and their generality to PennDOT issues across the Commonwealth. In addition, Penn State researchers prepared research problem statements and submitted them to the district in February 1999 to allow the district engineers to better understand Penn State's capabilities and interests.

2.1 Approach

After the initial meeting in the winter of 1999, a work order was prepared that responded to the issues identified and the needs to engage a broad constituency across the state. The initial areas of exploration were:

- Traffic and ITS - The testing of advanced traveler information systems and components of congestion management applications will be greatly facilitated by the test bed. In addition, emergency response to crashes and hazardous materials spills will be assisted by communications and management systems in the test bed.

- Geotechnical Engineering - Sections of the highway (e.g., bridge approach slabs) can be measured during construction and monitored during operations. This is an example of studies that seek to develop a firm understanding of the relationship among highway pavement performance, construction practices, and highway durability under actual loads and weather conditions.
- Structural Engineering - Advanced structural monitoring technologies have reached a level of maturity that now allows implementation for bridge management, condition evaluation, and response to loading. Components that can be considered for short-term and long-term monitoring include integral bridge abutments, horizontally curved bridge girders, slender piers, and pre-stressed strand development lengths.
- Materials and Construction - The performance of advanced materials and construction methods will be assessed, particularly advanced concrete mix designs.
- Pavement Performance - By integrating data obtained from the geotechnical evaluations and the mix design studies, direct evaluation of current pavement designs can be conducted. The advanced monitoring within the test bed should improve understanding of how designs perform under actual conditions. (Note: separate plans were developed for Portland cement concrete pavement management and bituminous pavements with the concurrence of PennDOT).

After the initiation of the work order, and with the support of District 2 and PennDOT headquarters, an additional technical area was added:

- Hydrology and Hydraulics - PennDOT is expending significant resources in environmental compliance monitoring. Automated monitoring systems can be directly tested. Further, enhanced instrumentation can be used to calibrate hydrologic models that can be used in place of direct monitoring, saving PennDOT additional millions in monitoring costs.

To stimulate discussion in each of these six areas, white papers were prepared by Penn State faculty. These white papers were based upon the issues identified in prior meetings with PennDOT, the knowledge of the researchers, and their perception of research opportunities in the areas. These white papers are contained in Appendix A.

In addition to the six technical areas, there was a need for discussion of how the test bed fit into PennDOT training needs and laboratory developments at Penn State. All of these issues were addressed in a series of meetings throughout the duration of the work order. Table 2 summarizes the work order tasks and the mechanism by which these tasks were completed.

Tasks 1 through 5 and the added hydrology task were addressed through the organization of an I-99 conference, which was held at Penn State on July 23, 1999. Penn State researchers worked cooperatively with PennDOT District 2 to develop an invitation list, which included other PennDOT districts, PennDOT headquarters, FHWA, consultants and contractors engaged in I-99 work, and local transportation agency representatives from the Centre County area.

Table 2. Summary of Task Completion.

Task	How Addressed	Comments
1. Traffic and ITS	Conference – July 23	Workshop at I-99 conference.
2. Geotechnical Engineering	Conference – July 23	Workshop at I-99 conference.
3. Structural Engineering	Conference – July 23	Workshop at I-99 conference.
4. Materials and Construction	Conference – July 23	Workshop at I-99 conference.
5. Pavement Performance	Conference – July 23	Workshop at I-99 conference.
6. Infrastructure Management Center	Conference – July 23; Meetings August and September	Discussed during meetings at PennDOT headquarters July 9, and periodic meetings with District 2.
7. Advanced Education and Continuing Education	Meetings August and September	Educational issues have been the subject of numerous meetings between Penn State and PennDOT.
8. Coordination with Penn State Laboratories	Meetings August and September	Laboratory and test track facility development have been the subject of numerous meetings between Penn State and PennDOT.
9. Prepare Final Report	This Document	Final report.

Attended by 112 professionals, the conference was organized into a series of structured interactions aimed at:

1. Identifying technical issues of importance for PennDOT and other highway agencies that are addressable through test bed experimentation.
2. Reaching consensus on the research approaches needed to attack the problems, again focusing on those feasible within the test bed.

In addition to this meeting, a meeting was held on July 28, 1999 with a focus on bituminous pavement performance. At each step and within each meeting, care was taken to ensure that there was time for discussion and input from the involved parties. As such, the recommendations of the conference may be treated as a consensus concerning a research and development plan for the test bed. Numerous smaller meetings, some one on one, were held later in the summer concerning the remaining issues. Appendices B and C contain the breakout group meeting minutes that were reported to the attendees at the meeting. Table 3 summarizes the workshop attendance and the distribution of attendees by affiliation. The category "other" consists of attendees representing industry trade organizations, local transportation agencies, or other state transportation departments. See Appendix B for a full list of attendees.

Table 3. Summary of Workshop Participants by Affiliation.

	Number of	Affiliation				
Workshop Title	Participants	PennDOT	PSU	Private	FHWA	Other
Hydrosystems	11	5	3	1	1	0
Geotechnical	12	10	2	3	0	0
Materials and Construction	24	8	5	7	1	4
Pavement Performance - Rigid	23	6	3	4	2	1
Structures	16	4	7	2	1	0
Traffic and ITS	18	3	12	2	0	1

Note: An additional 8 attendees were not assigned to specific workshops but visited several.

The conference on July 23 was carefully structured to facilitate open discussion and to solicit broad input on technical issues. Guidance was provided to Penn State facilitators to conduct four rounds of discussions:

1. Allow broad input from all workshop attendees concerning technical issues of importance to them;
2. Consolidate technical issues to those with highest priority;
3. Generate research approaches that respond to the priorities from step 2; and
4. Rate the approaches as to those likely to be most effective in the test bed framework.

As a result of this approach, a large number of technical issues were identified and discussed in each of the workshop sessions. As the day proceeded, many alternative research approaches were also considered. The total number of issues and approaches identified in each technical area is summarized in Table 4. Details of the deliberations in each workshop session are contained in appendices.

Table 4. Workshop Identification of Technical Issues and Research Approaches.

Workshop	Number of Technical Issues Identified	Number of Research Approaches
Hydrosystems	15	6
Geotechnical	20	7
Materials and Construction	23	4
Pavement Performance- rigid	23	9
Structures	17	5
Traffic and ITS	20	5
Totals	118	36

2.2 Summary

The summarizing of over 118 technical issues and 36 research approaches consumed significant time and staff resources after the conference. As expected, many of the technical issues identified in the sessions overlapped; issues identified in construction and materials were also found to be important in pavement performance, for example. This was expected, but the effort necessary to combine and correlate the issues was underestimated.

Penn State faculty met several times after the conference to combine and reduce down the technical issues and research approaches to a manageable number. Penn State faculty also added cost estimates to the research approaches. The next two chapters describe the technical issues of greatest importance (Chapter 3) and the most promising research approaches (Chapter 4). These may be considered as consensus recommendations from the conference, as they were voted on and prioritized by the attendees.

Chapter 3

Conclusions: Summary of Technical Research and Development Issues Addressed by I-99 Advanced Transportation Technology Test Bed

3.0 Introduction

This chapter presents a summary of technical issues identified at the I-99 conference as high priority for consideration in the proposed I-99 research plan. The issues are divided into four application areas: bridges, pavements, hydrosystems, and traffic and ITS. These represent a consolidation of issues identified during the July 23 conference. Only the top-rated issues are discussed in this chapter. Penn State faculty reviewed the records of the meetings and consolidated a very comprehensive set of recommendations into a smaller, more coordinated set. Problem statements that were similar in scope and importance, but recommended in more than one workshop, were consolidated to eliminate duplication.

One of the strongest findings of the conference was the consistency in the perceptions of the major technical issues confronting PennDOT and highway transportation. The summary in this chapter represents a strong consensus of what issues need to be addressed.

Many worthy ideas were generated during the discussions at the conference; the interested reader is referred to the detailed issue statements in Appendix B. Research statements, responding to these high-priority issues, are described in Chapter 4.

3.1 Bridges

The I-99 project provides an opportunity to assemble and analyze valuable data concerning the performance of bridge structures, both during construction and in service. Because design is well underway, it is not feasible to develop and test new structural systems for this project. However the designs that are being developed include several that offer excellent opportunities for advanced study, with the expectation of influencing subsequent designs on other facilities.

In the bridges category, five issues were identified as research needs due to their significance to the Commonwealth and their applicability to the I-99 test bed concept: skewed and curved bridges, integral abutment bridges, seismic design requirements, concrete bridge decks, and geotechnical aspects of bridge foundations.

3.1.1 Movement and Stresses in Skewed and Curved Girder Bridges

Improvements are needed in design methodologies for skewed and curved girder bridges due to the difficulty of accurately predicting movement and stresses in the structure during construction and service. The Curved Steel Bridge Research Project (CSBRP), initiated by FHWA, examines curved steel bridge behavior in the laboratory. Penn State faculty have been intimately involved in this testing for the past 2 years and expect to be in the future. The I-99 test bed offers the unique opportunity to instrument and study skewed and curved composite bridges during actual construction and service life. This is an important enhancement of FHWA laboratory studies, will lead to an improved understanding of behavior, and will provide a basis for validating and improving design procedures. This project was the highest-rated problem emerging from the structural meetings at the conference.

3.1.2 Inability to Prevent Deck Cracking

Each year transportation agencies across the United States invest tens of millions of dollars in concrete bridge deck repair, replacement, and rehabilitation. These projects not only consume resources, but cause significant delays for the motoring public on highways and roads. The I-99 project provides an opportunity to study the effects of numerous variables influencing deck cracking, including mix design, placement sequence, and curing; reinforcement details; girder stiffness, length, and spacing; traffic volume; loading; and impact. Recent developments in the technology of high-performance concrete could lead to significant improvements in concrete deck performance. The significant number of bridges planned for construction in this project provides an excellent opportunity to perform controlled studies of the variables involved. This problem was the fourth-rated issue in the structures sessions but was the top-rated issue in the materials and construction sessions.

3.1.3 Design of Integral Abutment Bridges

Integral abutment bridges provide a solution to the problems associated with expansion joints in bridges. A number of design approaches have been proposed; however, field data are needed to validate proposed methods and to provide needed information on performance of integral abutment bridges, including prediction of movement and long-duration stresses. The design issues include orientation of piles and design assumptions, performance of approach slabs, and effects of soil pressure on back walls and wing walls. Skew effects are also important for integral abutment bridges. The I-99 test bed offers a unique opportunity to examine these deficiencies and the behavior of integral abutment systems as a whole both during and after construction. This issue was rated third in importance within the structures meeting but was part of the highest-rated project in geotechnical engineering at the I-99 conference. For these reasons it is listed as second in importance.

3.1.4 Construction of Bridges using New Seismic Designs

Recent changes in requirements for seismic design have led to problems due to congestion of reinforcement in bridge piers. Many of the required details are based on experience with earthquakes in California. The appropriateness of these requirements for bridges constructed in the mid-Atlantic region needs to be closely examined.

Specifications have resulted in reinforcing configurations for new bridge piers that are in some cases not constructible due to the congestion of reinforcing bars. A question of proper concrete consolidation arises as well as the actual performance of this type of detail in a severe seismic event. In addition, a perceived whole-scale seismic inadequacy of existing bridge support structures in the mid-Atlantic region, particularly single- and multi-column pier bents, has developed. Current small-scale studies are underway to investigate the actual capacities and seismic survivability of existing designs; however, a larger-scale study is warranted to evaluate the effects of an eastern seismic event on bridge pier details of this type. Alternate reinforcing details are required for mid-to low-risk regions to facilitate constructibility and to reduce the impact on construction delays due to this congestion.

The I-99 project provides an opportunity to document problems experienced during construction of piers with these seismic details in conjunction with a study to establish seismic design requirements for Pennsylvania. This was identified as the second-highest-rated issue during the structures sessions at the I-99 conference.

3.1.5 Geotechnical Problems Associated with Bridges

A number of geotechnical issues associated with bridge construction are amenable to study in the I-99 project. These include methods for site investigation and characterization, approaches and foundations for bridges, lateral loads on structures, use of alternative abutment fill materials, pile design values, and development of appropriate bearing capacity estimates for rock. These issues received the top-priority ranking in importance during the geotechnical meeting at the I-99 conference.

3.1.6 Summary

Virtually every aspect of bridge design, construction, and evaluation was discussed during the I-99 conference and in multiple workshops. A common methodology in many discussions was the need for accurate, reliable, long-term monitoring of bridges from construction through actual performance with real loads under extant conditions. Attendees recognized that extensive monitoring provides the opportunity to test new monitoring and sensor technology as part of a broader program to develop and use databases for specific construction and materials information, and quantitative test data that would be available to PennDOT for future projects.

3.2 Rigid Pavements

Pavement performance was a major focus of the I-99 conference, with a session dedicated to rigid pavements and a later meeting organized around flexible pavements (see Appendix B). Discussion of important issues and research approaches overlapped with those in materials and construction and geotechnical engineering.

It is understood that portland cement concrete pavement will be used exclusively on the I-99 project. Opportunities for research aimed at improving performance of rigid pavement can be categorized into six groups: monitoring and evaluation, truck-pavement interaction, subbases, concrete mix design, pavement design, and construction.

3.2.1 Design and Performance of Pavement Subgrades

Issues concerning pavement performance raised during the conference included joint movement, seasonal behavior of subgrades, subbase drainage efficiency, and crack development. Attendees agreed that these issues are critical to the success of a pavement design and that critical questions exist about current design practices. There is a need to conduct *long-term* monitoring of rigid pavements to learn more about the four referenced issues.

Subbase performance is an important aspect of overall pavement system performance. Variables include gradation and thickness of subbase, uniformity, and various subbase treatments. Uniformity of subgrade can be evaluated using the Falling Weight Deflectometer. Design for frost also needs to be considered. Better methods to assess and control compaction of subgrades and embankments are needed. Methods to control pavement cracking near underground pipes are also needed. The effectiveness of geosynthetic separators between pavement sections and subgrades could be evaluated in this project.

Information collected through a systematic monitoring program would provide a valuable database for improvements in design and construction of pavement. The I-99 project provides unique opportunities for monitoring. Attendees supported the development of a detailed instrumentation plan that could be used for selection and installation of sensors. These topics were the top-rated set of research studies recommended from the rigid pavement group.

3.2.2 Use of Recycled Materials

Opportunities for use of recycled materials should be evaluated. There are significant opportunities to test and evaluate a range of products in a number of different engineering applications. PennDOT personnel at the materials sessions were particularly supportive of this issue. Pennsylvania DEP is also strongly supportive of initiatives in this area. While not the highest-rated issue in any single session, this topic was mentioned at several sessions and has strong support from PennDOT.

3.2.3 Documentation of Construction Practices

There is a need to carefully document and evaluate construction practices, materials (including variability), and effectiveness of inspection to evaluate their effects on pavement performance. Innovative bidding and contract procedures as well as bonus/penalty criteria could be considered. This topic was highly rated at the rigid pavement workshop; it is ideally suited to graduate student activities and interests, and may even extend to undergraduate support as well.

3.3 Hydrosystems

Potential research areas in hydraulics and hydrology were identified in five areas: erosion and sediment controls, hydrologic modeling, hydrologic monitoring, stream restoration, and wetland design.

3.3.1 Improved Modeling of Surface and Subsurface Water Quantity and Quality

The I-99 corridor is being subjected to unprecedented levels of monitoring for water quality and quantity. While there are unique aspects of the watershed in the region that argue for this treatment, a concern was expressed at the I-99 conference that monitoring at this level may reasonably become the norm. The cost associated with this monitoring, over a ten-year period, is several millions of dollars. There is a need and an opportunity to calibrate accurate project-scale models of water quality and quantity, which can obviate the need for the monitoring, or reduce its duration.

Hydrologic modeling of subsurface and surface quantity and quality would include selecting areas to model along the South Bald Eagle Creek watershed and collect and analyze all of the data generated to date. Additional monitoring needs would be identified and the model would then be calibrated. The ultimate objective would be to develop a predictive water quantity and quality model that can reduce the amount of monitoring that is required by federal and state agencies. This issue received the highest-priority rating in the hydrosystems workshop at the I-99 conference.

3.3.2 Evaluation of Erosion and Sediment Controls

Approved erosion and sediment controls should be evaluated to determine the best management practices (BMPs). This would include review of current literature, current BMPs and Pennsylvania methods to evaluate practices; monitoring BMPs in place; and evaluating field changes and responses to determine why they are done and their relative success.

3.3.3 Evaluation of Stream Restoration

In the area of stream restoration, it is suggested that a case study on Laurel-Oliver Run Complex, including the review and design procedures of current restoration methodologies, be developed. Regional curves could be developed. Sediment and transport need to be monitored to assess the impact of the stream restoration practices at hydraulic structures such as culverts or bridges.

3.3.4 Evaluation of Man-Made Wetlands

The I-99 project provides an opportunity to review the objectives, methods, and designs for creating, enhancing, and preserving wetlands. Criteria and methods for evaluation of wetland design and objectives would be determined.

3.4 Traffic and ITS

Despite being located in a rural area, the I-99 test bed offers opportunities to use Intelligent Transportation Systems to solve traffic and other problems for the region and the Commonwealth. One of the most important needs in this area identified at the I-99 conference was the effective deployment and management of snowplows and other winter maintenance equipment. Use of advanced technologies would support PennDOT's "maintenance first" strategic plan, allowing the agency to continue to provide safe, comfortable, and improved winter travel for more of its citizens. In addition to management of roadways during adverse weather, ITS systems can provide accurate, timely information to travelers during adverse weather and during special events in the region. These systems will enhance the safety of travel and continue to support the special activities that add real dollars to the jurisdictions in the region.

3.4.1 Vehicle Deployment for Improved Winter Maintenance and Hazardous Materials Incidents

Maintenance needs include the development and testing of routing and scheduling algorithms for snow removal vehicles, and automated guidance for maintenance vehicles. Weather and roadway condition monitoring systems would be used to provide information to PennDOT on the locations needing surface treatment. Vehicles would be dynamically deployed to areas of greatest need, enhancing the quality of travel.

There is also a need to provide timely response to incidents and emergencies, including response to hazardous material spills. Conference attendees recognize that these spills pose a significant risk in remote rural areas. As we attempt to manage these incidents, there is a need to have better signing and other infrastructure to allow timely communication to drivers on the road.

3.4.2 "Smart" Highway Illumination and Signing

Highway signs convey largely static information that does not change with conditions or adapt in real time to enhance driver visibility. There is a need to improve highway signing to enhance safety performance and reduce the occurrence of crashes in adverse weather and visibility conditions.

3.4.3 Traveler Information and Special Event Response

A central location is required for receipt and processing of incident information, along with video surveillance cameras and monitoring of weather and roadway conditions. This traffic management center would support all the projects listed in this section and allow ready access and processing of data from the test bed.

Chapter 4

Recommendations: Research and Development Plan for I-99

4.0 Background

The issues related to improving Pennsylvania's highway infrastructure have been carefully considered. The technical knowledge exists to construct an infrastructure that is both economical and long lasting. After conducting comprehensive discussions with PennDOT, FHWA, and industry leaders and reviewing data from other states, a course of action can be implemented that will make I-99 a working laboratory for highway infrastructure. The plan outlined in this chapter is a comprehensive research effort to address many of the Commonwealth's and the Nation's important issues in highway design, performance, and construction.

The highway test bed is meant to be a long-lasting research program with an initial 5 years of intense daily activity by a broad spectrum of researchers, followed by an annual monitoring and educational component. The plans call for changes in selected structural and pavement design details, concrete mixture designs and material specifications in portions of the highway project. These selected changes will be monitored and evaluated with control sections to determine the optimum design and construction practices. The proximity of the project to Penn State provides a valuable educational experience for current and future PennDOT engineers and technical personnel. In the process of integrating instrumentation, construction documentation, and performance data, educational resources will provide a full-scale learning environment for future highway department engineers and contractors: a field-training site with performance criteria measured from construction to eventual replacement. This component is the long-lasting legacy to the Commonwealth that may pay the greatest dividends.

The research plan can be divided into four major components

A. Bridges
B. Pavements
C. Hydraulics
D. Traffic and ITS

Each component provides an important part of the research and has the potential to substantially improve the quality of the highway system. The knowledge gained from the research will be implementable throughout the Commonwealth and will enhance PennDOT's leadership role in the nation's program of transportation advancement. Table 5 summarizes the recommended research plan.

Table 5. Summary of Recommended Project Costs.

Project Title	Cost ($ 000's) Year 1	Year 2	Year 3	Year 4	Year 5	Total
1. Curved and skewed bridge movement and stresses	$200	$200	$200	$200	$200	$1,000
2. Long-term durability of bridge decks	$160	$160	$160	$80	$80	$640
3. Integral abutment movement and stress	$150	$150	$150	$150	$150	$750
4. Bridge seismic design standards	$150	$150	$150	-	-	$450
5. Geotechnical investigation for bridge foundations	$200	$200	$200	$100	$100	$800
6. Design and performance of pavement subgrade	$150	$150	$150	$100	$100	$650
7. Use of by-product and recycled materials	$100	$100	$100	$70	$70	$440
8. Contract monitoring	$70	$70	$70	$70	$70	$350
9. Modeling water quality and quantity	$125	$125	$125	$125	$125	$625
10. Erosion control best practices	$50	$50	$50	$50	$50	$250
11. Stream restoration	$100	$100	$100	$100	$100	$500
12. Wetland design evaluation	$125	$125	$125	$125	$125	$625
13. Hydrologic monitoring	$60	$60	$60	$60	$60	$300
14. Winter and hazardous materials incident response	$220	$220	$120	-	-	$560
15. Smart highway illumination and signing	$250	$250	$250			$750
16. Traveler information and traffic management	$295	$295	$70	-	-	$660
TOTAL	$2,405	$2,405	$2,080	$1,230	$1,230	$9,350

4.1 Bridge Research

Bridges in Pennsylvania suffer from a variety of design and durability issues. Some of these are isolated and some interrelated with other issues. The following issues are the most relevant and implementable on the I-99 project:

4.1.1 Prediction of Movement and Stresses in Curved and Skewed Structures

This issue received the highest-priority ranking in the structural discussion group. Increased implementation of curved and continuing construction of skewed bridges for both new construction and replacement projects indicates that improvement is needed in design methodology, particularly in the behavior of these systems during construction and effects of composite construction on force distributions. The research project discussed below will address this issue as it relates to structures planned for the I-99 test bed.

Outline of Research Plan: The research approach will combine current prediction models with in-situ field evaluation to establish better design and construction practices. The results will include best practice guidelines for design and construction of skew and curved girder bridges. The tasks to accomplish this research project objective are as follows:

1. Perform a literature review.
2. Perform finite element analysis and design field instrumentation.
3. Conduct data acquisition during construction phases.
4. Document construction sequence and as-built structure.
5. Interact with consultants/original designers to establish predicted behaviors.
6. Perform controlled load testing.
7. Validate current design methodology and construction sequence.

PennDOT, Penn State and FHWA will jointly agree upon the variables and scope of work. This project will examine behavior of a curved composite plate girder system and a selected number of skewed bridge systems through extensive field and analytical studies. The bridges will be instrumented during the construction phase and performance data will be collected over an extended period. Controlled field tests will be performed at various stages of the bridge life to examine behavior (flexural, shear, combined flexure and shear, deflections), and results from these studies will be compared to analytical and existing laboratory results. It is intended that this project will (1) provide comparative data to analytical models and experimental results from the CSBRP, (2) develop improved design guidelines specific to skewed and curved composite bridges in Pennsylvania, and (3) develop detailed and simplified analysis guidelines for curved and skewed composite bridges in Pennsylvania.

Impact: This project will develop an accurate design approach for horizontally curved composite girder bridges, both for the construction phases of the structure and the completed, in service phase. The project will also provide criteria from which an efficient analysis of a curved composite system can be obtained using either commercially available software or approximate methods. An extensive data set documenting the behavior of composite steel girder systems within the I-99 Advanced Transportation Technology Test Bed will also be provided.

Estimated Research Cost: $200,000/year for 5 years, with a long-term monitoring cost of $25,000 every 2 years. Approximately $100,000 of this cost is supplies, materials, sensors, and monitoring equipment.

4.1.2 Long Term Durability of Bridge Decks

This issue was the number-one priority in the material and construction group and the fourth highest in the structural discussion group. The issue has long-term financial and maintenance implications for Pennsylvania's highways. The research project will increase the life of bridge decks throughout the Commonwealth.

Outline of Research Plan: The research approach will integrate high-performance materials, improved construction practices, and comprehensive monitoring to document the best practice for long-service-life bridges. Results would include guidelines for the design and construction of bridge decks. The seven tasks envisioned in this work are as follows:

1. Develop and use improved concrete mixture designs for bridge decks to reduce permeability, rate of hydration, and chloride diffusion based on performance specifications;
2. Reduce the shrinkage cracking in bridge decks by (a) reducing the related early-age cracking through mandatory moist curing practices (e.g., fogger, cotton mats or burlap), (b) timing of curing measures (e.g., immediately after placement, 30 minutes, or 1 hour), and (c) length of curing measure (e.g., 3 days, 7 days, or 10 days);
3. Extend the life of bridge decks by using alternative reinforcement (e.g., stainless steel, fiber reinforced polymers, steel or polymer fiber);
4. Create a "best practices" document for casting, curing, and mixture designs;
5. Compare performance of decks cast under normal contractor procedures and those using best practices procedures, then analyze the results;
6. Develop a list of variables and document those on a sample group of bridges (pre-cast, composite, or other similar groupings); and
7. Develop a database of design and as-build materials and in-service performance characteristics for all the bridges on I-99 project.

The variables to be included will be from the following list.

- Permeability reduction with surface barrier treatments, pozzolans, and admixtures;
- Corrosion reduction with alternative reinforcement, FRP, stainless steel, synthetic fibers or steel fibers, and by elimination of chlorides deicers; and
- Cracking reduction by optimizing concrete mixture proportions, curing regimes, concrete maturity, and maximum temperature.

The results will be analyzed and correlated with standard laboratory test methods, the job site information, and bridge characteristics (girder stiffness, length, spacing, loading, traffic frequency, and maintenance actions).

A proposed scope of work would impact approximately 7 to 10 deck sections with a life expectancy of 50 years. This would include varying the mixture design, curing techniques, and reinforcing material in these decks. It would be proposed to place these HPC decks on representative sections of the project. Each deck would be inspected and documented thoroughly by researchers throughout construction, and monitored after construction. The deck thickness, construction methods, formwork, and overhead will not be affected by this work. This project will change the proportions of concrete mixtures, curing methods and materials, and materials for reinforcement (C10 only). These changes may increase or decrease the cost of some materials to the job, but will not typically change the handling or placement of the materials.

Impact: Transportation agencies across the United States invest tens of millions of dollars in concrete bridge deck repair, replacement, and rehabilitation. These projects not only consume resources, but cause significant delays for the motoring public on highways and roads. The important variables influencing bridge deck performance must be controlled and studied in order to determine factors that result in the most durable bridge deck. The I-99 test bed offers a unique opportunity to conduct such a study of 100+ bridge decks and to create a database of long-term and short-term effects of these variables.

Estimated Research Cost: $160,000/year for the first 3 years and $80,000 for the following 2 years, with a long-term monitoring cost of $8,000 every 2 years. Approximately $80,000 of this cost is supplies, materials, sensors, and monitoring equipment. This will be supplemented with FHWA supplying the HPC mobile testing laboratory. FHWA has committed to supplying the project with the high-performance concrete showcase mobile laboratory and in making the project an HPC Showcase for national interest.

4.1.3 Methodology to Predict Movement and Stresses in Integral Abutments

There is no methodology available to reliably predict movement and long-duration stresses in integral abutment bridges. The proposed project will examine the behavior of integral abutment bridges through field and analytical studies to better evaluate the short- and long-term behavior of this bridge construction to enhance this as an alternative to past construction.

Outline of Research Plan: Selected abutments, piles, and major components of jointless bridges will be instrumented to monitor field behavior during construction and over extended periods of time. Previously encountered problems such as preventing degradation of the approach slabs and efficiently orienting piles beneath the abutment sill still exist when integral abutment designs are used. The I-99 project offers a unique opportunity to examine these deficiencies and the behavior of integral abutment systems as a whole, both during and after construction. Sensors measuring strains, relative motions, and temperature changes will be placed in areas that are typically inaccessible when completed structures are studied. For instance, behavior of the approach slabs and compression seals under daily and long-term temperature variations will be studied along with soil pressure influences on the backwalls and wingwalls and behavior of piling beneath the abutments. Experimental data will be compared to predictions from common computational design tools. A series of analytical studies will be initiated to determine a best approach for predicting forces developed within various parts of the abutment system. Tasks include:

1. Perform a literature review.
2. Perform finite element analysis and design field instrumentation.
3. Conduct data acquisition during construction phases.
4. Document construction sequence and as-built structure.
5. Interact with consultants/original designers to establish predicted behaviors.
6. Perform controlled load testing, both short and long term.
7. Validate current design methodology and construction sequence.

Impact: This project has the potential to influence the design of all common highway short-span bridges in the Commonwealth. Constructing bridges without expansion joints will result in significantly less bridge maintenance for this structure type, longer girder life due to absence of leaking joints, lower dynamic effects imposed on the bridge due to elimination of the "bump," and improved ride quality for the motoring public.

Estimated Research Cost: $150,000/year for 5 years. Approximately $100,000 of this cost is supplies, materials, sensors, and monitoring equipment.

4.1.4 Seismic Design Standards for Bridges in the Mid-Atlantic Region

This was the second-ranked priority in the structural discussion group. Recently adopted seismic design provisions in the *AASHTO Bridge Design Specifications* have resulted in reinforcing configurations for new bridge piers that are in some cases not constructible due to the congestion of reinforcing bars. This issue arises from highly congested rebar conditions as well as the potential requirements for retrofit of existing bridges that result from recently released seismic design provisions. Economics and constructibility necessitate an evaluation of the recently adopted seismic design provisions to determine their suitability for bridges in the mid-Atlantic region.

Outline of Research Plan: A question of proper concrete consolidation arises as well as the actual performance of this type of detail in a severe seismic event. In addition, a perceived whole-scale seismic inadequacy of existing bridge support structures in the mid-Atlantic region, particularly single and multi-column pier bents, has developed. Current small-scale studies are underway to investigate the actual capacities and seismic survivability of existing designs; however, a larger-scale study is warranted to evaluate the effects of an eastern seismic event on bridge pier details of this type. Alternate reinforcing details are required for mid- to low-risk regions to facilitate constructibility and to reduce the impact on construction delays due to this congestion.

1. Perform a literature review.
2. Assess seismic hazard to highway bridges in the mid-Atlantic region.
3. Identify design/construction problems associated with mitigation of seismic issues.
4. Investigate the option of revising the seismic design provisions for the mid-Atlantic region and Pennsylvania from what has been accepted practice in California, as the seismic risk may be considerably different.

5. Develop cost-effective and constructible seismic design provisions for highway structures in Pennsylvania.

Impact: It has been estimated that incorporating suitable reinforcing details and more accurately assessing the seismic event magnitude for the mid-Atlantic region relative to new and existing construction will translate into several hundred million dollars of savings. The results of this study may potentially impact the entire mid-Atlantic region bridge population.

Estimated Research Cost: $150,000/year over 3 years.

4.1.5 Geotechnical Site Investigation for Bridge Foundations

Current PennDOT site investigation practices for bridge foundations have been described as inadequate, particularly in karst terrain where rock conditions are often highly variable. Bridges in Pennsylvania are largely founded on piles or other deep foundations. Highly variable subsurface conditions result in great uncertainty in deep foundation design and construction. The Department would greatly benefit from a better definition of subsurface conditions, including top-of-rock profile and quality of rock.

Outline of Research Plan: This research effort proposes to conduct a comprehensive study of subsurface conditions at bridge sites prior to, during, and after construction to help develop more comprehensive practices of subsurface characterization. The proposed research will include the following tasks:

1. Conduct additional and alternative site investigation techniques, including both surface and borehole seismic wave propagation (e.g., SASW and cross-hole), and ground penetrating radar (GPR) prior to construction to provide more comprehensive subsurface characterization.
2. Instrument individual piles prior to installation to enable monitoring of long-term performance.
3. Closely monitor driving performance of piles during construction to assess variability of subsurface conditions and in-situ pile capacity.
4. Assess post-construction subsurface conditions using wave propagation and GPR techniques to provide detailed subsurface characterization for long-term monitoring of piles and approach-slab fills.
5. Monitor long-term behavior of piles (e.g., settlement and skin friction) and approach-slab fills (e.g., in-situ properties and settlement).
6. Correlate original subsurface characterization with long-term behavior and develop recommendations for future subsurface investigation practice.

Impact: The proposed research outline addresses several of the high-priority problem areas identified in the geotechnical engineering workshop, including the first priority on subsurface assessment.

Estimated Research Cost: The proposed research can be conducted as follows:

\$200,000 per year for 3 years yields:	\$600,000
\$100,000 per year for 2 years yields:	\$200,000
Project Total:	\$800,000

4.2 Pavement Research

Pavements in Pennsylvania suffer from a variety of design and durability issues. Some of these are isolated and some are interrelated with other issues. The following issues are the most relevant and implementable on the I-99 project.

4.2.1 Design and Performance of Pavement Subgrades

A number of high-priority problem areas related to pavement subgrades were identified in both the geotechnical engineering and pavement performance workshops, including compaction control of subgrades, subgrade stabilization, and design subgrade support values that capture both spatial and seasonal variability. The I-99 facility offers a number of opportunities to monitor existing practice and to investigate alternative subgrade characterization methodologies.

Outline of Research Plan: Current state-of-the-art pavement design methodologies base subgrade support characterization on the modulus of elasticity and shearing strength of subgrade soil. The subgrade modulus is typically considered the key parameter, yet typical practice does not include direct assessment of modulus due to the difficulty of obtaining adequate characterization for in situ conditions. The SASW method of seismic wave propagation is a well-documented technique for determining in situ modulus. The moduli of natural materials can be measured and used for design inputs. Measured moduli can also be used as a direct assessment of compaction quality, rather than relying on the more indirect assessment based upon unit weight. For subgrade support purposes, the modulus is much more relevant than the unit weight.

The proposed research will evaluate the usefulness of wave propagation moduli as a parameter for assessing subgrade support and for controlling subgrade compaction along the I-99 facility. Several test locations will be selected to:

1. Assess the reasonableness of the measured modulus values and characterize the spatial variability of the existing soils.
2. Assess the modulus values measured during construction as a means of compaction control and to assess the spatial variability of the subgrade soils upon which the pavement will be constructed.
3. Measure the modulus values at selected locations at several points in time to assess the seasonal variability of the subgrade support.
4. Instrument pavement joints at both the spatial and seasonal monitoring locations to assess the impact of subgrade variability on pavement performance.

5. Correlate subgrade modulus measurements with long-term behavior and develop recommendations for future characterization practice.

Estimated Research Costs: The proposed research can be conducted as follows:

$150,000 per year for 3 years yields:	$450,000
$100,000 per year for 2 years yields:	$200,000
Project Total:	$650,000

4.2.2 Using Recycled and By-Product Materials

PennDOT identified this area as one of the top areas of interest. The use of recycled and industrial byproduct materials in construction can be used to improve the technical properties of the project and eliminate the need to discard the Commonwealth's valuable natural resources. This project will address the most pressing needs and create guidelines that will impact all future highway construction in Pennsylvania.

Outline of Research Plan: There is a need to create a well-documented, archived and monitored interstate highway project containing sizeable quantities of recycled materials. The proposed research would assist in integrating up to 20,000 tons of recycled and byproduct materials into the I-99 project. This would include: (1) mixed colored glass and foundry sand in pipe backfill, embankments, and flowable backfill; (2) tires in sound walls and embankments; (3) fly ash in concrete and flowable backfill; and (4) recycled materials content of other highway materials (lane delineators, traffic cones, paint, striping, signage, barricades, and curbing). The project would perform the following:

1. Monitor and evaluate the in-situ use of glass and tires in non-roadway applications.
2. Provide protocol to all PennDOT projects on the use of glass and tire materials.
3. Monitor and analyze the results of using fly ash at 25 percent replacement level in concrete to reduce the cracking potential from heat and salt-related issues while simultaneously improving the ASR resistance of concrete.
4. Evaluate and validate the use of recycled and by-product materials in flowable backfill.
5. Monitor and validate other components of the I-99 project that contain recycled materials (e.g., sound walls and stabilized base material).

The material would be required to meet or exceed the same performance standards that current materials meet and would be used in applications where they will be environmentally benign.

Impact: Incorporating these materials into embankments, sound walls, pipe backfill and control low-strength material for the I-99 project is an excellent opportunity to document and monitor the use of these materials. The project would use and monitor the use of approximately 20,000 tons of recycled materials.

Estimated Research Cost: $100,000/year over the first 3 years and $70,000 for the following 2 years. Approximately $100,000 of this cost is supplies, sensors, materials, and monitoring equipment. PennDOT's Memorandum of Understanding with the Department of Environmental Protection may offset the construction costs.

4.2.3 Contract Administration

This topic was among the top issues in the areas of both the materials and construction group and the pavements group.

Outline of Research Plan: This project will involve the monitoring of the schedule progress on several phases of the work using the linear scheduling or line-of-balance technique. The progress using linear scheduling will be compared to the critical path method (CPM) approach of schedule monitoring, which is a contract obligation of the contractor. The purpose of the monitoring will be to compare linear scheduling to CPM to determine if linear scheduling provides a better understanding of potential delays and their causes. Improvements in this area will enhance the likelihood that PennDOT can avoid costly litigation before the Board of Contract Claims. The tasks envisioned in this project are as follows:

1. Obtain and become familiar with a computerized linear scheduling algorithm prepared by researchers at Iowa State for the Iowa DOT.
2. Obtain the CPM schedule prepared by the contractor.
3. Through discussions with PennDOT personnel and the contractor, prepare a linear schedule for the project showing constraints in the way the work is planned and executed.
4. Attend weekly progress meetings to ascertain the progress of the work.
5. Update the linear schedule weekly and compare the update to the corresponding CPM schedule.
6. Meet monthly with PennDOT personnel to discuss the comparison highlighting any constraints or potential delays observed in either of the two schedules.

Scope: The proposed work will cover several sections (contracts) on the I-99 project. The planning for this project will begin prior to construction with the development of preliminary schedules that are based on discussions with PennDOT personnel. Schedules with several levels of detail will be prepared. Monitoring will begin as the construction begins. Rates of progress will be documented weekly. Comparisons will be made with the updates provided by the contractor. Throughout this project, graphical schedule updates will be posted in the Departmental office at the job site.

Impact: PennDOT, in documenting schedule progress to avoid contract claims for delay, expends considerable energy. The CPM approach is used for this purpose. Unfortunately, CPM has limitations. First, it is not well suited to linear-type projects. Second, it models schedule delays when there is a shutdown, but is less suited to delays caused by reduced contractor efficiency. Also, from the viewpoint of judicial proceedings, the CPM is often complicated, and schedule consultants can reach differing conclusions even when using the same base information. It is felt that linear scheduling can effectively overcome the above-cited limitations of CPM. This could save PennDOT considerable time and monies in avoiding disputes and potential judicial awards to the contractor.

Estimated Research Cost: $70,000 for 5 years. Approximately $20,000 of this cost is for supplies and materials.

4.3 Water Resources Issues

The hydrosystems group addressed two objectives: the first was to identify water-related problems that could or would result from the I-99 construction through Centre County and that the issues could be translated to other PennDOT projects or to highway construction in general. The second objective was to come to a consensus of the membership of the group as to what items might be addressed in future research projects.

4.3.1 Hydrologic Modeling of Subsurface and Surface Quantity and Quality

Develop a predictive water quantity and quality model that can reduce the amount of monitoring that is required by federal and state agencies. At the present time PennDOT is required to monitor quantity and quality of water at several locations upstream and downstream of the I-99 highway right-of-way where the embankment divides the watershed. This is not just a site-specific problem to I-99; with future highway construction, the task of monitoring will most likely become even more rigorous and costly.

Outline of Research Plan: Determine areas along the South Bald Eagle Creek watershed that are being monitored, and collect and analyze all of the data generated to date. Determine additional monitoring needs, calibrate the model, and compare the results to the design. There are several models that have been developed by researchers in the Department of Civil and Environmental Engineering at Penn State that are mechanistic-based watershed models. The models can simulate river/stream flow, overland flow, and saturated/unsaturated subsurface flow through media modules and can be adapted to account for the hydrodynamics, sediment transport, pollutant, fate, and transformation. It is proposed that the models be modified over a three-year time period and that the model selected be calibrated and used for prediction over the next two years. The intent of the calibration of the modeling would be to develop a good predictive tool that would allow PennDOT to significantly reduce the required 10 years of monitoring, and it would develop a tool that could be used for future sensitive environmental areas.

Impact: The impact of the research would be to reduce the monitoring effort to which PennDOT is presently committed. The hope would be to reduce the monitoring effort by 50% on the I-99 construction and to illustrate the usefulness of the model's predictive capabilities for future highway construction projects.

Estimated Research Cost: Instrumentation would be required and it would have to be determined whether the instrumentation would be done by the consulting firm, Skelly and Loy Inc., or by Penn State. The estimated cost of this project is approximately $125,000 per year, which would include two to three faculty and four graduate students.

4.3.2 Evaluation of Approved Erosion and Sediment Controls to Determine Best Management Practice

Outline of Research Plan: Review current literature, current Best Management Practices, and Pennsylvania methods to evaluate practices; monitor BMPs in place; and evaluate field changes and responses to determine why they are done and their relative success. This project would be extended to two years after the completion of the I-99 corridor to complete the evaluation of the BMPs.

Impact: At the present time PennDOT and other state highway departments are required to select BMPs from a list of past practices without regard to their effectiveness. Some of the practices are required at all construction sites but may not perform adequately. It seems foolish to implement something that doesn't work. The intent of the research would be to develop evaluation and measurement procedures to effectively assess BMPs that are currently being developed.

Estimated Research Cost: It would require one faculty member and several graduate students over the life of the project. Instrumentation would be required, and it would have to be determined whether the instrumentation would be done by the consulting firm, Skelly and Loy Inc. or by Penn State. The estimated cost of this project is approximately $250,000/five years, which would include 25% of a faculty and three graduate students.

4.3.3 Stream Restoration

Outline of Research Plan: PennDOT will be modifying approximately 20,000 feet of local streams during the construction of the I-99 project. Because of the sensitivity of the eco-system of the streams due to the highway construction, the stream restoration methodologies being implemented become important.

Task 1. Develop a case study on Laurel-Oliver Run Complex including the review and design procedures of current restoration methodologies. Develop regional curves, monitor sediment and transport, and assess the impact of the stream restoration practices at hydraulic structures such as culverts or bridges.

Task 2. Evaluate stream enhancements along the I-99 corridor. The effort for Part B would be dictated by the level of effort that PennDOT and Penn State personnel would deem necessary.

Impact: The stream restoration practices of today are totally different from how practitioners attempted to structurally confine natural stream drainage systems in the past. Because the stream restoration methodologies are new, it is not yet clear how effective they will be in preserving the natural stream system, and it is the intent of this research to quantify these new practices.

Estimated Research Cost: The estimated cost for part A will be approximately $100,000 per year for five years, which would include one faculty and several graduate students. The cost for Part B would be dictated by the level of effort that PennDOT and Penn State personnel would deem necessary.

4.3.4 Evaluation of Wetland Design

Review the objectives, methods, and designs for creating, enhancing, and preserving wetlands. Determine the criteria and methods for evaluation of wetland design and objectives. Some of the cost of monitoring wetlands has been included in the monitoring portion of the action items. However, because wetland mitigation is a problem for every state transportation department, it would be extremely beneficial to (1) determine criteria and methods to evaluate the wetland design that the state agencies and the regulatory agencies can accept, and (2) use these criteria to evaluate the I-99 mitigation plans.

Outline of Research Plan: Perform a literature search to determine what other state and federal agencies have done for creating, enhancing, and preserving wetlands. Establish criteria that are satisfactory to all of the agencies involved in the permitting process to evaluate the effect of wetlands. Once the evaluation criteria have been established, then it would be implemented to evaluate the wetlands that PennDOT will be using on the I-99 construction.

Impact: At the present time PennDOT does not have a one-acre-for-one-acre or one-acre-for three-acre wetland mitigation policy; however, without an understanding of the effectiveness of man-made wetlands, each highway project becomes negotiable with an unknown cost.

Estimated Research Cost: To accomplish this task it is estimated that $125,000 per year would be needed to fund two faculty and several graduate students.

4.3.5 Hydrologic Monitoring

Outline of Research Plan: Determine the existing monitoring system and determine the need and time line for additional monitoring. Assess the impact to the hydrologic processes including seep wetlands and subsurface pavement drainage. Extensive monitoring is currently being proposed and done by Skelly and Loy Inc. Additional monitoring would be needed to determine the effectiveness of the wetland mitigation. The instrumentation and the extent would have to be determined in a broader scope of work.

Estimated Research Cost: approximately $300,000 over five years, which would include one faculty and several graduate students. It should be noted that the cost of this project is combined with topic 4.3.1 in Table 1. The scope of work is complimentary.

4.4 Recommendations for Research on Traffic and Intelligent Transportation Systems (ITS)

The conference attendees in the traffic and ITS workshop identified a wide range of technical issues and potential research actions. The projects ranked highest by attendees tended to be in the areas of enhanced maintenance, safety, and protection of the environment.

4.4.1 Vehicle Deployment for Improved Winter Maintenance and Hazardous Materials Incidents

Snow/ice management personnel currently lack access to real-time roadway condition information that can be used in their optimal deployment. In addition, dynamic route optimization algorithms (used to direct salting and snow removal vehicles to priority locations most efficiently) are not used. Similar problems occur with hazardous materials incidents; travelers are not provided accurate and timely information, and emergency response teams may not take advantage of the latest technologies. This research action has three interrelated projects.

Improved Winter Maintenance

Outline of Research Plan: Through the use of advanced sensor technologies and other surveillance devices, estimates (or forecasts) of current (or future) snow levels and the presence of ice on short stretches of roadway can be made. This information can be automatically relayed to a central computer where procedures are run to optimally route and schedule snowplows and salting/gritting vehicles given updated information on weather and roadway conditions. The conceptual framework and algorithmic steps can be developed for routing snowplows and salting/gritting vehicles along the I-99 corridor, under real-time information concerning dynamically varying roadway conditions and priority levels. Five tasks are envisioned for this project:

1. Perform a literature review.
2. Develop algorithms and determine the type and quantity of field data needed for data collection.
3. Perform data collection.
4. Calibrate and validate algorithms developed, as necessary.
5. Implement validated algorithms.

For this project, the high-priority infrastructure needs are for weather and roadway condition monitoring equipment.

Impact: Decreased operational costs and improved driver workload balance in day-to-day operations; increased snow-clearing capabilities.

Estimated Research Cost: The Penn State cost is $50,000/year for 2 years.

Improved Incident and Hazardous Material Release Information Dissemination

A "smart" mayday system would be installed along the I-99 corridor. The system would have direct contact with PennDOT maintenance facilities, local police, fire, EMS, and medical facilities, resulting in decreased response times and allowing the appropriate response agencies to be notified of the nature of the incident. GPS and communications technology (such as cellular technology) could be utilized.

Outline of Research Plan: The use of real-time information concerning existing roadway conditions, as well as accurate forecasting techniques of future conditions, can be employed to select routes for motorists with reduced probability of incidents. The conceptual framework and algorithmic steps will be developed for determining optimal routes (i.e., routes with the minimum probability of incidents due to weather and roadway conditions) that exploit real-time and predicted information concerning dynamically varying and probabilistic roadway attributes (such as travel time and risk of incidents). The resulting techniques must fuse historical, real-time, and predicted information obtained from surveillance and feedback mechanisms and can be used to direct and redirect vehicles, particularly those vehicles carrying hazardous materials, in order to reduce the likelihood of an incident en route. Such a system can be employed along the I-99 corridor, including the surrounding roadway network, and should be incorporated within the overall traffic management plan for the region. Five tasks are envisioned:

1. Perform a literature review, and assess other such systems developed and implemented.
2. Develop incident prediction/classification algorithms.
3. Develop incident response procedures.
4. Implement the procedures developed in the previous tasks.
5. Assess the effectiveness of the implemented procedures, and adjust as appropriate.

For this project, the high-priority infrastructure requirements are weather and roadway condition monitoring and video surveillance cameras.

Impact: Reductions in incident frequency and delay to motorists.

Estimated Research Cost: Approximate Penn State cost is $120,000/year for three years.

Enhanced Emergency Vehicle Response to Hazardous Material Spills

In the event of a hazardous materials spill, trained personnel need to be informed, completely and quickly, and take immediate action using specialized equipment. Lack of appropriate information concerning the substance(s) involved, the magnitude of the incident, and the most rapid route to the spill site increase the chances of severe environmental damage resulting from the incident. Mobile communication technologies provide emergency response units with real-time information concerning roadway incidents involving vehicles carrying hazardous substances and other highway accidents.

Outline of Research Plan: The advent and increasing deployment of mobile communication technologies has made it possible to provide emergency response units with real-time information concerning roadway incidents involving vehicles carrying hazardous substances and other highway accidents. Such information includes the type of substance the vehicle is carrying, the severity and exact location of the incident, and the best route to the incident, and it enables emergency responders to answer a hazardous situation quickly with the appropriate equipment and number of trained personnel. Decision support technologies are needed (including computer algorithms and analytical methodologies for real-time information processing, risk assessment, response action, and route selection) that utilize and integrate historical, real-time, and predicted information. Roadway conditions, travel times, and specific details of the incident or trauma can be used to develop useful strategies and response instructions, to reduce the impact of hazardous materials spills along the I-99 corridor. Four tasks are envisioned:

1. Perform a literature review.
2. Develop algorithms for real time information processing.
3. Develop strategies for response action and route selection instructions.
4. Implement and assess the strategies developed.

For this project, the high-priority infrastructure requirements are weather and roadway condition monitoring and video surveillance cameras.

Impact: Decreased response times and increased efficiency during spill containment and incident management phases; minimization of environmental damage.

Estimated Research Cost: Approximate Penn State cost is $50,000/year for two years.

4.4.2 "Smart" Highway Illumination and Signing

I-99 provides the opportunity for research, development, and full-scale implementation of roadway and interchange illumination technologies. A roadway illumination facility could be developed to test different types of roadway and interchange illumination.

Outline of Research Plan: The facility would be composed of tracked gantries that could be used to vary the lateral and longitudinal placement and the height of luminaires. It could also be used to test different types of lighting systems (i.e., various types of bulbs, fiber optic, etc.). The systems could also be used to test various types of "smart" lighting that varied with ambient lighting and weather conditions. Five tasks are envisioned:

1. Perform a literature review to identify all components required for the facility.
2. Identify/develop types of lighting systems to be tested.
3. Prepare the facility/equipment plans required for testing.
4. Develop procedures for testing new/proposed lighting systems.
5. Implement and assess the procedures developed.

For this project, the high-priority infrastructure requirements include a "smart" highway illumination facility with feedback and control capabilities.

Impact: The facility provides a test bed for research and development of roadway and interchange illumination and provides grounds for full-scale implementation of the illumination technologies. It is expected that funding can be developed from the private sector to support research in illumination and advanced signing as programs have been underway at PTI for several years in these areas.

Estimated Research Cost: Approximate Penn State cost is $250,000/year for three years.

4.4.3 Traveler Information and Special Event Response Center

Traveler information, when provided by a variety of sources, can contain unreliable, conflicting. and contradictory messages that undermine and may defeat the purpose of information provision. In addition, there is a need to closely coordinate special event occurrence in rural Centre County with the provision of traveler information. Two separate projects are develop within this area: travel information and special event response.

Travel Information Dissemination

Outline of Research Plan: There is a need for the creation of a real-time information clearinghouse (Traveler Information Center, TIC) for the I-99 corridor that collects complementary and overlapping information, verifies the validity of information, and broadcasts messages to all travelers using different media of communication. Information outlets should include Internet, radio, variable message signs, 800 numbers, and daily fax for a fee and other services. This facility will also provide the backbone for daily operation of sensors and communications equipment elsewhere in the test bed. The following six tasks are envisioned:

1. Perform a literature review to identify all components required for the center.
2. Develop algorithms for real-time information processing.
3. Develop data collection procedures.
4. Develop dissemination procedures.
5. Implement the data collection/dissemination procedures.
6. Evaluate and adjust as necessary the procedures developed.

Impact: Increased compliance with suggestions (e.g., traffic rerouting), decreased traveler costs, and an enhanced public relations profile.

Estimated Research Cost: Approximate Penn State cost is $225,000/year for two years.

Traffic Management and Parking During Special Events

Athletic events, concerts, and other special events held at both Beaver Stadium and the Bryce Jordan Center currently generate large volumes of traffic on the roadways in the vicinity of these two facilities. In addition to the increased demand, the presence of a large number of drivers that are not familiar with the State College area (nor the real-time availability of parking facilities), creates an additional strain on the highway network.

Outline of Research Plan: Drivers, especially those unfamiliar with the area, need to be properly guided to the designated parking lots, avoiding areas of increased congestion, during special events at Beaver Stadium and the Bryce Jordan Center. Real-time information regarding the availability of parking and current traffic conditions will reduce the delays and travel times experienced by drivers. Advanced technologies can be used to collect and disseminate such information along the I-99 corridor, as drivers approach the State College area. The following five tasks are envisioned:

1. Perform a literature review.
2. Develop algorithms and strategies for traffic management and parking.
3. Outline hardware/software components required to implement the strategies developed.
4. Deploy the strategies developed, including hardware/software components.
5. Evaluate and assess the traffic management and parking system developed.

For this project, the high-priority infrastructure elements required are variable message signs (special events routing), vehicle detection (to obtain flow, speed, occupancy, vehicle classification on I-99 corridor and the adjacent system) and real-time traffic signal control capabilities throughout the I-99 corridor.

Impact: Reduced travel times and delays, and reduced probability of incidents during special events.

Estimated Research Cost: Approximate Penn State cost is $70,000/year for three years.

4.5 Summary

The I-99 Advanced Transportation Technology Test Bed will offer the Pennsylvania Department of Transportation a laboratory by which to test technologies that will enhance its "Maintenance First" Strategic Plan. The test bed will provide PennDOT with the ability to reduce the life-cycle cost of highway and bridge infrastructure in the state, saving millions of dollars annually. The plan is broad-based, including elements of the planning, design, construction, operation, and maintenance of a highway facility.

This plan for the I-99 test bed represents the collective effort of many attendees of the I-99 conference as well as the product of many additional meetings. Implementation of the plan will allow PennDOT to capitalize on the unique opportunity to create a world-class facility on one of the last sections of interstate highway in the United States.

APPENDIX A: WHITE PAPERS

INTEGRATED FACILITIES FOR TESTING AND RESEARCH

The laboratory and testing facilities at Penn State University are available to complement field testing activities at the I-99 test bed. Laboratories are available to support traffic and ITS studies, materials testing, pavement testing, structural testing, and sensor development. In addition, the outdoor PTI Transportation Research Facility provides opportunities for full-scale testing of pavements and structures, and related activities.

1. Traffic and ITS

The ATLAS, MANTIS, and TeAM laboratories located in the Transportation Research Building provide opportunities for computer-based traffic management and traffic simulation studies. Items required to support the laboratory portion of the proposed studies are as follows:

Upgrading the ATLAS lab (computers, hardwire-interconnections, software):	$100,000
Upgrading the MANTIS lab (computers and software):	$100,000
Upgrading the Optipath lab (computers, and software):	$100,000

2. Geotechnical Engineering

The soils testing laboratory in the Department of Civil and Environmental Engineering is available for soils testing as required in conjunction with field monitoring studies. In addition, the outdoor Transportation Research Facility provides opportunity for full-scale testing under controlled conditions. It is anticipated that data acquisition and other equipment needs for the proposed research will amount to approximately $50,000.

3. Structural Engineering

The Structures Laboratory, located in the Department of Civil and Environmental Engineering, has the capacity for testing structural members up to 40 feet in length under static and cyclic fatigue loading. In addition specimens can be tested under impact loading. The outdoor Transportation Research Facility contains a full-scale bridge test site previously used for testing segmental concrete bridges. A proposal is being developed to incorporate an additional bridge test site as part of a new durability track for pavement studies. Proposed upgrading of the Structures Laboratory is anticipated to cost approximately $250,000.

4. Materials and Construction

Materials research is a major focus area at Penn State University and research facilities are available for materials research at both the microscopic and macroscopic levels. Considerable expertise is available at the Materials Research Laboratory for fundamental studies of cement-based materials and sensor technology, while the PTI laboratories contain facilities for fabricating and testing concrete samples. Laboratories are also available on campus for the study of composite materials, wood products, and other materials.

5. Pavement Performance

The durability track at the PTI Transportation Research Facility is available to conduct full-scale studies of pavement performance under controlled conditions. In addition, the concrete materials laboratory is available for the study of concrete mix designs for pavement applications.

6. Environmental and Hydrosystems

The Department of Civil and Environmental Engineering houses a fully equipped hydraulics laboratory containing a 50-foot-long steel tilting flume and related equipment, as well as the Kappe Environmental Laboratories. At the present time, it is not anticipated that laboratory improvements will be required for these laboratories in connection with the I-99 test bed project.

PTI TRANSPORTATION RESEARCH FACILITY IMPROVEMENTS

A comprehensive plan is being developed for upgrade and improvement of the outdoor Transportation Research Facility. Many of these proposed improvements would be of direct benefit to the proposed I-99 test bed project. The main components of the plan are:

1. Transportation Research Laboratory:

This multi-purpose building is intended to house research facilities for bus testing, vehicle systems, large-scale structural testing, autoclaved concrete fabrication, and pavement performance. A portion of the required funding has been provided by the Federal Transit Authority in connection with bus testing research. The total cost of the building is estimated at $2,250,000.

2. Durability Test Track:

A proposal is being developed for construction of a new durability track, primarily for Superpave validation studies. The new track will be located north of the existing durability track. While the I-99 pavement will be of concrete construction, PennDOT has a strong interest in implementation of Superpave technology and there is potential for undertaking field studies of Superpave applications on other highways in the region with related studies on the new durability track. The estimated cost of development of the new durability track is $5,000,000.

3. Crash Testing Research Center:

Although not directly related to the I-99 test bed project, plans are being developed for upgrading of the crash test facility at a cost of approximately $500,000.

WHITE PAPER FOR I-99 CONFERENCE: HYDROLOGY AND HYDRAULICS

Peggy A. Johnson and Arthur C. Miller

The construction of a highway in the vicinity of streams and wetlands can affect the stream environment in a number of ways: (1) wetlands can be drained or altered; (2) streams can be straightened, relocated, or culverted; and (3) stream channel erosion and deposition patterns can change. In the following paragraphs we address each of these issues associated in general with most highway construction, but specifically with the construction of I-99.

Wetlands

The construction of highways can cause significant changes in the drainage pattern of the surrounding lands. These changes can have detrimental effects on downslope wetlands. Thus, monitoring of wetlands and drainage areas is essential to assure proper functioning of the wetlands. A well-planned monitoring program has the additional advantage of providing data that can be used to calibrate existing hydrologic computer programs for this region.

In addition to monitoring, a wide variety of materials, including recycled materials, are available for highway construction that provide a range of permeabilities for increasing or decreasing drainage from beneath the highway. The use of such materials can provide proper drainage so that downslope wetlands continue to function as they did prior to the disturbance. Monitoring of the drainage from these materials will provide valuable data for improvement of wetlands mitigation and hydrologic software calibration.

Stream Restoration

It will be necessary at many locations along the I-99 construction path to straighten, relocate, culvert, or otherwise modify many stream reaches in order to accommodate the highway. As is common practice in Pennsylvania and many other states, a specified number of feet of stream length is required to be restored elsewhere for every foot of stream that is altered along the highway construction path. Stream restoration varies from planting vegetation along the banks to the creation of meanders and changes in the channel geometry. The required level of restoration is highly dependent upon the objectives of the restoration project. Objectives include habitat restoration, aesthetic improvement, and bank stabilization. For each identified restoration site associated with the I-99 project, the objective of the restoration and the design necessary to meet the objective will have to be determined.

Stream restoration designs may include one or more of the following:

- **Channel modifications**. This includes meander platform and hydraulic geometry changes that involve changes to the actual stream channel itself. The design is a function of the flow rate, sediment load, and physiographic region.

- **In-stream structures**. In-stream structures include crib walls, riprap, vanes, weirs, and deflectors. These structures are a part of most restoration projects. They are used to provide stability and to enhance flow diversity for habitat improvement.

- **Bank and riparian vegetation.** Vegetation is nearly always a part of a restoration project. Vegetation provides bank stability as well as shade and a food source to improve habitats.

There is currently minimal guidance available regarding the level of restoration that is needed, the design of the restoration components, and the post-construction monitoring that is required. Given the large number of feet of stream restoration required associated with the I-99 project, significant advancements could be made in terms of assessing the needs and design of stream restoration projects associated with highway construction. In addition, post-construction monitoring could provide data needed for the development of restoration guidelines that would be used for the construction of future highways in Pennsylvania, as well as for I-99.

Stream Erosion

Modifications to stream channels and changes in hydraulic parameters due to road construction can result in a change in erosional patterns. The results can include damage to bridge foundations, perched culverts, and erosion at roadway embankments. Bridge scour is a common problem at bridges across the United States. There are three types of scour: bed degradation, contraction, and local. Contraction and local scours are caused by the bridge itself, due to the obstruction caused by the bridge. Although any type of scour can result in bridge failure, a bridge that is properly designed can avoid problems associated with local and contraction scours. Channel bed degradation, on the other hand, can be far more difficult to predict and design for. It can be significant in channels that have been straightened and can also be caused by an increase in discharge, which could in turn be caused by a change in drainage following highway construction. Although there are several models available to predict channel adjustments, they are generally not applicable in central Pennsylvania due to the uncertainty in sediment transport equations contained within the models for this region. Studies that focus on qualitative or quantitative models for predicting channel bed adjustments following highway construction are needed, so that stream crossings can be designed appropriately.

Stream channel erosion at culverts can result in several problems, including perching of the culvert if the channel bed degrades, silting of the culvert entrance, and destabilization of channel banks. The bed-degradation problem is similar to that discussed for bridges. Silting at culverts is often caused by a shallow culvert slope or an overwidened entrance. Silting results in a capacity reduction; thus, the culvert cannot convey the design storm. If erosional problems are severe at the downstream end of the culvert, the channel banks may destabilize. These problems often require continued maintenance over the life of the culvert. An ability to predict erosion and deposition at culverts would thus be beneficial to the I-99 project as well as to future highway projects.

Monitoring Water Courses

The hydrosystems faculty met with Bert Kisner and Kim Bartoo of PennDOT's Engineering District 2-0 to discuss opportunities for research that would be of mutual interest. Due to the possible impact that the I-99 highway could have on the quantity and quality of water, PennDOT is being required to monitor quantity and quality of water at several locations upstream and downstream of the highway where the embankment divides the watershed. The monitoring is to reduce the time for mandatory monitoring. We discussed the opportunity of implementing mechanistic-based watershed models that have been developed at Penn State. The models are comprised of river/stream, overland, and saturated/unsaturated subsurface media modules and can be adapted to account for hydrodynamics, sediment transport, pollutant, fate and transformation. It would seem plausible that checking three years of calibration and two years of prediction against the collected data would decrease PennDOT's overall monitoring time by half. This would be a substantial savings for I-99, as well as for other projects that PennDOT will encounter.

WHITE PAPER FOR I-99 CONFERENCE:POTENTIAL RIGID PAVEMENT PERFORMANCE STUDIES FOR THE I-99 TEST BED

Introduction

The Pennsylvania Department of Transportation (PennDOT) has successfully used rigid pavements on heavily-trafficked roadways for decades. The department has continually sought improvements in designs, materials, and monitoring in order to maximize the initial life spans of these pavements, and to extend their lives using effective rehabilitation. However, available materials, construction techniques and equipment, truck loads, and other factors continue to evolve and change. Some of these changes make improved designs possible; others pose new and ever-increasing design challenges.

For example, PennDOT is currently engaged in an intensive forensic study to determine the causes of premature mid-slab cracking on some rigid interstate pavements constructed permanent slab curling, and base type/construction play parts in these distresses. Although the final conclusions have not yet been reached regarding the causes of the slab curling, changes in materials and construction to achieve other improved performance factors, such as early opening to traffic, may have played a part.

The construction of the I-99 pavements provides an opportunity to monitor and study some of the current factors influencing the performance of rigid highway pavements in Pennsylvania. It also provides the opportunity to implement and monitor some design improvements and feature variations, to determine their cost-effectiveness for PennDOT. The mainline recommended pavement designs include 10 to 11 inches of plain cement concrete pavement on 4 inches of stabilized base and 6 inches of subbase.

Some of the potential experiments and design variations are described here. The purpose of the conference will be to discuss these and other potential ideas from the participants, and to reach consensus on which experiments are most important to the short- and long-term performance of rigid pavements in Pennsylvania. The goal will be to provide recommendations and solutions for some of PennDOT's most pressing problems and questions, while providing high-performing pavements for the I-99 facility.

Potential Design Variations

Joints

Overall, poor joint performance and reduced overall pavement performance due to failure or under-performance of joint features continue to be the major causes of premature failure and rehabilitation of rigid pavements in Pennsylvania. Increasing traffic loads and use of alternate base types have confounded joint performance evaluations. Inadequate joint load transfer, both initially and after some years of use, is probably the single largest contributor to early pavement distress. During rehabilitation operations, dowel bars are sometimes found to be significantly corroded. Epoxy coating is a common approach employed to minimize dowel corrosion. Non-corrosive bar materials may be warranted for extended pavement life.

Failure of joint seals is also a persistent problem. In fact, some states are reconsidering the use of joint sealants or are switching sealant designs. One alternate design is the sawing of only narrow joints, and filling them with sealant material or even leaving them unsealed. New materials may serve more effectively at keeping such a narrow joint filled and decreasing the total infiltration of moisture and incompressables. Sawing procedures may also have an impact on joint sealant performance and overall joint durability. The feasibility of using HIPERPAV for the I-99 project should be explored.

In order to evaluate features for improving joint performance and optimizing joint cost, sections of 1000-foot length could be constructed with single variations on the standard design to include selections from below. Although recent work has shown improved load transfer with dowel bar inserters, some alternate designs may require placement with baskets, due to the short test section length. Therefore, controls may need to be constructed with both dowel bar inserters and baskets.

Dowel materials:	steel, stainless-steel clad, composites, filled stainless-steel tubes
Dowel shape:	round, oval or elliptical bars
Dowel coatings:	epoxy or Tectyl, form oil, bituminous, plastic, other materials
Dowel spacing:	12-in spacing, concentration of dowels near corners, wheelpaths
Dowel location:	on the neutral axis, above or below the axis
Dowel installation:	dowel bar inserter, baskets
Outside slab width:	widened to 14 ft (1.5 ft past stripe)
Joint seal design:	single cut (not widened) with filler, shaped reservoir with compression seal, shaped reservoir with poured sealant
Joint spacing:	15 to 20 feet

Prior to construction, laboratory and computational analysis would be conducted to assure the construction of designs expected to improve performance. For example, computations would include finite element analysis of dowel shapes and configurations. Laboratory testing should include determination of pullout forces, bearing stresses under the dowels, and dowel looseness or deflections under static and dynamic loading. Long-term analysis would include performance evaluations and determination of deterioration mechanisms. Monitoring of joint movements would allow verification/improvement of joint seal designs and specifications.

Bases

The base type and construction for a rigid pavement has been found to affect its load-carrying capacity and its joint performance. Open-graded base materials have been used to improve drainage, while still providing a stable base. However, some construction problems and suspected performance problems have been experienced with open-graded bases. Other drainable bases have been used with cement or asphalt stabilization. The benefits of side drains (with and without permeable bases) have also been questioned by recent studies; day-lighting may be an alternate design.

Test sections with base course or drainage variations could be implemented on the I-99 pavement. All test sections would be designed for anticipated quality performance, and the variations in performance monitored to assess their cost-effectiveness.

Other Variations

Some of the other design variations that could be employed on I-99 pavements include:

- variation in longitudinal joint tie bar designs
- mixture variations (optimized gradations, cements)
- extended design life
- pavement surface texturing with regard to noise, skid resistance, and drainage

Other ideas for innovative research that could be conducted on I-99 without compromising the performance of the facility may well be brought up and explored by conference participants.

Monitoring

Extended performance monitoring will be essential to the success of any pavement-related experiment on I-99. Although the nature and quantity of monitoring required will depend on the selected experiments and analysis requirements, many of the monitoring needs can be anticipated.

In order to characterize climatic effects and separate them from load-related effects, careful environmental monitoring would be recommended. Potential activities include the monitoring of moisture, temperature, and frost. An on-site weather station would be needed. In addition, evaluation of sealant effectiveness and drainage may involve periodic use of tipping buckets.

Joint movements would be monitored. An evaluation of the performance of joint seals and improved joint seal design procedures must include an understanding of the patterns of joint movement. The American Association of State Highway and Transportation Officials (AASHTO) joint opening model is inadequate; a mechanistic model has been developed but requires calibration. In addition, slab curling may be monitored.

Overall performance measures would also be regularly collected. Periodic measurement of faulting, profile, stiffness, and joint load transfer would be conducted. Distress surveys would also be required.

One of the most important monitoring activities, and perhaps worthy of an independent investigation, is the collection of traffic data. Information on truck classifications and weights will be essential to assessing the performance of joints and other design features. Particularly with very heavy trucks, the impact of their dynamic loads may be crucial in understanding the structural performance of the joints and of the overall pavement. Traditional load-equivalencies used in design may be inadequate for current truck weights and tire and axle configurations. The use of instrumented trucks and simulation models may be recommended to understand the interaction between the pavement surface/response and the applied loads.

Importance

Extensive research is currently being conducted on rigid pavement design and performance. Data is available from accelerated tests, LTPP, WesTrack, and other sources. It is important that the I-99 test bed pavement experiments be designed to complement other current research, and, most importantly, to address the specific needs of PennDOT. Monitoring and analysis activities should be designed to provide short-term answers for the department. Continued longer-term monitoring is necessary for a thorough understanding of the resulting pavement performance. he potential monetary savings to PennDOT resulting from improved rigid highway pavement performance and improved cost-effectiveness are tremendous.

WHITE PAPER FOR I-99 CONFERENCE: MATERIALS AND CONSTRUCTION FOR I-99 AND BEYOND

Introduction

The changes in materials technology and quality-control techniques have created opportunities for improving highway infrastructure. Through the judicious use of these technologies and techniques, the potential exists to reduce the maintenance costs and greatly extend the service life of the state's highways and bridges. The integration of design improvements can be clearly demonstrated and evaluated on the I-99 corridor from Port Matilda to Bellefonte in central Pennsylvania. The information gathered can be the platform from which the Commonwealth can launch a higher level of service and quality for the highway system.

The I-99 corridor offers the ideal opportunity to show that new technologies and material combinations can be integrated to create a superior product that has greater value than that achieved through current practices. Although we already use sound design and construction techniques in Pennsylvania, the I-99 corridor project provides a setting where multiple technologies and materials can be evaluated side-by-side under identical environmental and loading conditions. A superior highway is one that has extended life, reduced operation and maintenance issues, and is less expensive when considering construction, operation, and maintenance costs. In addition to these direct costs, the societal costs of lane closures and delays for maintenance (repair, rehabilitation, and reconstruction) are reduced for superior highways.

PennDOT's district personnel, designers, consultants, testing laboratories, and contractors, as well as personnel from the Pennsylvania Department of Environmental Protection, transportation departments in other states in the region, and the Federal Highway Administration, have made it evident that there are sound approaches for both reducing problems in the infrastructure and improving the current practices that have served us well. These approaches can be implemented to improve the roadway experience for the customer, increase the benefit/cost ratio to the taxpayer, and improve the environmental standing of the Commonwealth. Some of the ideas that have already been advanced to improve the long-term performance of highways and decrease the Commonwealth's total costs of construction, operation and maintenance include:

1) high performance concrete (HPC), to improve the long-term durability of bridge decks and pavements and to reduce the cost of bridge sub-and super-structures;
2) integration of recycled and byproduct materials, e.g. recycled glass component in embankments and fill areas, tires in soundwalls, foundry sand in flowable fill, and fly ash and ground granulated blast furnace slag in concrete and flowable fill;
3) construction monitoring systems to improve reliability of pile driving operations and document pavement smoothness;

4) technologies from the Strategic Highway Research Program (SHRP) to monitor and evaluate materials as they are being placed, e.g. ASR mitigation, and maturity meters; and
5) improved quality control/assurance technologies, that offer warrantee contracts with contractor input, collect better information on each segment of highway, and define performance for construction and operation.

Setting a Direction for I-99 in Pennsylvania

The simple guiding principle in this endeavor is roads and bridges that last longer, require less maintenance, and cause customers to be proud of what they have purchased. Thus, there is a need to discuss associated problems and potential approaches to making Pennsylvania's highways among the best quality and most cost efficient in the nation. From a materials and construction standpoint, this can be achieved by changing design standards, changing construction and operation practices, or both, to better serve the needs of the Commonwealth. The constructed highway infrastructure can be designed to last longer, be more environmentally friendly, and provide greater customer satisfaction.

The problems with highway infrastructure are not so great as to warrant a wholesale change in direction or design methods. The problems vary from the frequency and cost of repair, rehabilitation, or restoration, to the need for noise abatement in residential neighborhoods. These problems must be defined by field personnel and district engineers. The problems often lie in unanticipated loadings, changes in environmental conditions, or variability in materials or methods. The approaches to addressing these problems come from discussion, evaluation, and implementation.

Interstate 99 and future Pennsylvania highways can benefit from the known problems and the discussion of these issues. The I-99 section being constructed between Port Matilda, Pennsylvania and Bellefonte, Pennsylvania is an ideal location to evaluate and implement technically sound approaches to known problems. This stretch of interstate is located close to Penn State University, one of the premier universities in the United States and Pennsylvania's land grant institution. The University has the largest transportation research institute in the Commonwealth and trains many of PennDOT's engineers, managers and technical personnel. Combining these opportunities and resources will provide Pennsylvania with better highways and better-trained engineers and managers in the future.

Technical Ideas for I-99

Four initial areas of potential research/applications have been developed for I-99 through conversations with PennDOT and Pennsylvania Department of Environmental Protection personnel and others may come forward. These include:

1. Extending the life of concrete bridge decks through HPC technology;
2. Implementing maturity meters for in-situ concrete evaluation;
3. Developing a database for material and structural performance; and

4. Using recycled and by-product materials.

1. EXTENDING THE LIFE OF CONCRETE BRIDGE DECKS THROUGH HIGH-PERFORMANCE MATERIALS TECHNOLOGY

DESCRIPTION: The quality of reinforced concrete can be improved to increase the life cycle/cost ratio of bridges in Pennsylvania. National research and a few trial projects in other parts of the United States have shown that there are potential regimens that will improve the average life of bridges in Pennsylvania. PennDOT currently uses Type AAA concrete, epoxy coated reinforcement with 75-mm (3-in.) cover concrete. The current specification does not address alternative forms of corrosion-resistant reinforcement or performance criteria such as permeability, shrinkage potential, rate of hydration and conductivity of concrete. The development of concrete mixtures that meet maximum rates of hydration, conductivity, shrinkage, and permeability levels has the potential to increase the life of bridge decks by 10 to 50 years, while adding less than 5 percent to the cost of the bridge. The use of pozzolans (fly ash, silica fume, and metakaolin), ground granulated blast furnace slag, and alkali micro-silicates to meet performance criteria can be considered. These materials make the concrete impermeable to water and chloride ions. By starving the system of these critical elements and maintaining a pH environment of about 12.5 around the reinforcing steel, it is passively protected from oxidation and subsequent corrosion. The current mixture designs used in bridge decks often contain too much portland cement and that cement is too finely ground. These two elements contribute to increased shrinkage cracking and the ingress of chlorides from deicing salts. The use of epoxy coated reinforcing is a sound practice and has served Pennsylvania well. However, there are other systems that could extend the life of bridge decks to greater than 100 years.

SCOPE: The proposed scope of work on the I-99 project is to (1) develop and use improved concrete mixture designs for bridge decks to reduce permeability, rate of hydration and conductivity based on performance specifications; (2) reduce the shrinkage cracking in bridge decks by reducing the related early-age cracking; and (3) extend the life of bridge decks by using alternative reinforcement. The average life of bridge decks in Pennsylvania is approximately 25 years with the superstructure lasting approximately 50 years. The proposed decks will be designed to last a minimum of 50 years with a superstructure lasting 100 years. The construction methods, formwork, labor and overhead will not be affected by this work. This project will change the proportions of concrete mixtures and materials for reinforcement. These changes may increase or decrease the cost of some materials to the job, but will not typically change the handling or placement of the material.

2. IMPLEMENTING MATURITY METER FOR IN-SITU CONCRETE EVALUATION

DESCRIPTION: New technologies have been developed through the Strategic Highway Research Program (SHRP) aimed at assisting contractors and materials producers in controlling the quality of the materials used in highway construction. The maturity meter was one of the best technologies for immediate implementation. The science is very good and the meters are relatively inexpensive and simple to use. The maturity meter measures the degree of hydration of portland cement using a time vs. temperature function. This relationship is a measure of the exothermic reaction of portland cement, pozzolan and water. When compared to a control sample, the meter can more reliably estimate the strength development of the concrete in a pavement, bridge deck, precast concrete member, or similar product. The value of the technology is in its real-time strength prediction for prestressed tendon release, post-tensioning, early opening to traffic, construction staging and quality assurance. The technology accounts for curing conditions, initial materials temperature, ambient temperature conditions, and the insulating effects of forms and concrete thickness. An initial trial of the technology is currently undergoing evaluation for the 1999 construction season. Under this initial work order, PennDOT and Penn State University are developing protocol for the use of the technology throughout the commonwealth.

SCOPE: The proposed scope of work on the I-99 project is to (1) conduct a thorough and well documented use of the maturity meter technology, (2) implement associated specifications for quality control and quality assurance programs, and (3) allow the contractor to use the technology under supervision to ensure its proper implementation and interpretation. The work will create the maturity history of selected pavements and bridge decks to add to a materials and performance database. The research and test program will develop recommendations for the use of the maturity meters and provide a test bed to train PennDOT personnel.

3. <u>DEVELOPING A DATABASE FOR MATERIAL AND STRUCTURAL PERFORMANCE</u>

DESCRIPTION: Tracking the performance of material used in Pennsylvania is not possible with the current pavement and bridge inventory system. The system needs a database of more specific construction and materials information and quantitative test data, especially as more innovative methods and life extending techniques are used. Documenting the specific materials used in concrete pavements and in bridges and for prestressed concrete girders, substructures and decks is an important part of evaluating durability and lifetime performance.

Periodic quantitative evaluation of concrete provides a clear picture of the time-dependent properties (increasing strength and modulus, ingress of chlorides, shrinkage, decreasing permeability, conductivity and delamination). The videologging already done by PennDOT, tools developed in the SHRP program, and concrete tomography developed by the U. S. Army Corps of Engineers can greatly increase the quantification of the bridge and pavement performance. A database to monitor the long-term performance of I-99 will provide a blueprint for all districts to use for improving the life cycle of pavements and bridges in Pennsylvania. I-99 can be monitored in perpetuity to provide feedback for the commonwealth and other states. To reach the goal of a 100-year highway, the monitoring system and associated database must be maintained and used as a learning tool. The information can be put into a GIS format using FHWA protocol for long-term pavement performance and the bridge inventory system.

SCOPE: The proposed scope of work on the I-99 project is to (1) develop a materials and performance database for concrete in pavements and bridges along the highway; (2) conduct quantitative evaluation of concrete over time including permeability, chloride intrusion, conductivity, modulus, compressive strength, scaling, delamination, and tomography; and (3) provide a means for PennDOT and highway engineers to remotely monitor and learn from the database

4. USING RECYCLED AND BY-PRODUCT MATERIALS

DESCRIPTION: The Commonwealth is better served from an environmental standpoint when we reduce the barriers between divisions of government and seek out constructive solutions to common problems. The Commonwealth's highway infrastructure results in the creation of a great deal of waste materials (tires, asphalt, concrete, and steel). In addition, industry produces many byproduct and waste materials (fly ash, foundry sand, and blast furnace slag). Many of these byproducts and materials are clean, uniform, high-quality raw materials that can be used to construct and maintain infrastructure.

SCOPE: The proposed scope of work would assist in integrating recycled and byproduct materials into the I-99 project. It would (1) monitor and evaluate the in-situ use of glass and tires in embankment and fill applications in non-roadway applications to provide protocol to all PennDOT projects on the use of these materials; (2) monitor and analyze the results of using fly ash above the 15 percent replacement level in concrete to reduce the cracking potential from heat and salt while simultaneously improving the ASR resistance of concrete; (3) evaluate and validate the use of recycled and byproduct materials in flowable backfill; and (4) monitor and validate other components of the I-99 project that contain recycled materials (e.g. soundwalls and stabilized base material). The goal of this task would be to monitor the use of 20,000 tons of recycled materials.

WHITE PAPER FOR I-99 CONFERENCE: STRUCTURES ISSUES

Determination of Transfer Length in Prestressed Concrete Bridge Girders

Introduction/Background

There is a considerable body of recent research on the transfer of prestress force in prestressed concrete girders, most of it indicating that the current AASHTO values are unconservative. As a result of a 1988 FHWA directive, several researchers began investigations of the actual transfer length in prestressed girders. They found that, in general, the AASHTO value is unconservative in the sense of providing an underestimate of the mean value, or the inability to account for the widely observed variation in measured transfer lengths.

Lane (1994) reports average development lengths of 38.0 inches for 0.5 inch diameter strands and 45.4 inches for 0.6 inch diameter strands in multiple strand applications, compared to AASHTO values of 27.7 inches and 34.7 inches. Russell and Burns (1996) report wide variation in measured transfer lengths, but a mean of about 29.5 inches for 0.5 inch strand and 40.1 inches for 0.6 inch strand in single-strand applications. Logan (1997) finds very large differences among strand manufacturers in the ability of their strand to transfer prestressing force, which accounts, at least partially, for the wide variation observed in this and other tests. Buckner (1995) points out that the AASHTO formula for transfer length applies to 250 ksi strand and is not rational for use in 270 ksi low-relaxation strand. He recommends the use of initial prestress force for the determination of transfer length, and further questions whether the mean experimental values or a lower bound value should be used for calculations involving transfer length. On the other hand, Ahlborn, French, and Leon (1995) find the AASHTO formula to be reasonable for a pair of long-span, high-strength prestressed girders subjected to an extensive testing program, implying perhaps that concrete strength has a considerable impact on transfer length.

The calculation of end stresses at release in a prestressed girder requires accurate knowledge of the effects in the transfer zone. If the transfer length is overestimated, then the girder will be prestressed to a location closer to the end, and tensile cracking may result at release. If the transfer length is underestimated, then undercapacity under service loads may result. When end stresses were relieved by harping a percentage of the strands, the only transfer zone was at the ends of the girders. In these locations, it is unlikely to have large service load moments, and transfer zone effects could be managed by using a low value for the transfer length. At the present time, however, the practice is to debond a percentage of the strands, moving the transfer zone for some of the strands away from the ends of the girder. In these cases, a precise knowledge of the location and length of the transfer zone is necessary in order to balance the tensile stresses at release and the service load stresses.

Approach

Based on the findings of the literature review, an experimental investigation of the transfer length for the debonded strands in multiple transfer zones will be conducted. In this study, the girders to be used in the I-99 project will be subjected to a measurement program at the precast plants. The measurement of transfer length is conducted by finding strain differences in the concrete at the level of the reinforcement before and after release. Although this technique is very effective at end transfer zones where the concrete strain reaches approximately zero, its usefulness and effectiveness for interior transfer zones will be investigated by this study. Determinations of transfer length will be made for 0.5 inch and 0.6 inch strands, and compared to AASHTO standards and to analytical models existing in the literature.

Analysis

The implications of the experimentally determined transfer lengths on strand size, spacing, grouping, and debonding will be investigated by a variety of analytical tools. Finite element analysis will be employed to look in detail at the multiaxial stresses developed in end and interior transfer zones, to examine the probability of developing flexural cracks at transfer. The strain results of the models will be carefully compared to experimentally determined strains. Flexural analysis of precast pretensioned members will be conducted to determine the impact of potentially longer required transfer lengths on the detailed design of prestressed bridge girders.

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Performance of Integral Abutments

Introduction/Background

This project will examine the behavior of I-99 bridges designed using integral abutments through field and analytical studies. Abutments, piles, and major components of the I-99 jointless bridges will be instrumented so that the field behavioral can be monitored. The elimination of joints over intermediate piers and at bridge abutments has increased in popularity for both new designs and retrofit projects due to the dramatic reduction in maintenance costs associated with jointless structures. However, some problems, such as preventing degradation of the approach slabs and efficiently orienting piles beneath the abutment sill, still exist when integral abutment designs are used. The I-99 project offers a unique opportunity to examine these deficiencies and the behavior of integral abutment systems as a whole both during and after construction. Sensors measuring strains, relative motions, and temperature changes will be placed in areas that are typically inaccessible when completed structures are studied. For instance, behavior of the approach slabs and compression seals under daily and long-term temperature variations will be studied, along with soil pressure influences on the backwalls and wingwalls, and behavior of piling beneath the abutments. Experimental data will be reduced and analyzed and compared to predictions from common computational design tools. A series of analytical studies will be initiated to determine the best approach for predicting forces developed within various parts of the abutment system. New methods for designing integral abutments will then be suggested.

Evaluation of Curved Composite Bridge System Behavior

Introduction/Background

Increased implementation of curved bridges for new designs and replacement projects indicate that improvement is needed in the design methodology recommended in the AASHTO *Guide Specification for Horizontally Curved Highway Bridges* (1993). These changes affect web and flange slenderness limits, transverse stiffener spacing intervals, behavior of curved systems during construction, and effects of composite construction on force distributions within curved bridges. The Curved Steel Bridge Research Project (CSBRP) was initiated by the FHWA in 1992 to reopen examination into curved steel bridge behavior and to improve current design methods. The project examines behavior of various full-scale curved plate girder sections under different loading scenarios through a series of full-scale tests. Data produced from these tests will be used to provide impetus for modifications to the AASHTO design equations. While the CSBRP provides an extensive set of information on the behavior of curved girder bridges, including curved composite girder bridges, limited information is available from field investigations of these structures. Outside of work completed by Galambos et al. (1998) for the Minnesota Department of Transportation, no recent full-scale field study tests have occurred. However, the I-99 Advanced Transportation Technology Test Bed presents a unique opportunity to instrument and study a curved composite bridge system during its construction and service life.

This project will examine behavior of a curved composite plate girder system through extensive field and analytical studies of a representative structure. The selected bridge will be extensively instrumented during the construction phase, and data will be generated over an extended period of time. Controlled field tests will be performed at various stages of the bridge's life to examine aspects of its behavior (flexural, shear, combined flexure, and shear) and results from these studies will be compared to analytical and laboratory (CSBRP) results. This project is intended to (1) provide comparative data to analytical models and experimental results from the CSBRP; (2) help develop improved design guidelines specific to curved composite bridges in Pennsylvania; and (3) develop detailed and simplified analysis guidelines for curved composite bridges in Pennsylvania.

Approach
FIELD RESEARCH. Most of the tasks will be accomplished under this activity, which encompasses all duties completed while at the bridge site. The tasks consist of placement and activation of instrumentation; documentation of construction sequence; documentation of as-built structure; completion of controlled tests; completion of random tests (permit loads); and periodic visual inspection and instrument replacement.

COMPUTER/DESIGN RESEARCH. Computer research will occur at Penn State and will center on the creation of a large number of analytical models. In addition, a number of studies of current design equations and procedures will take place. Task items associated with this activity include the creation of preliminary finite element models from the design plans; sensitivity studies of the finite element models; modification to finite element models from field measurements; and comparisons between experimental, analytical, and design behavioral predictions.

Anticipated Results and Benefits
This project will develop an accurate design approach for horizontally curved composite girder bridges, both for the construction phases of the structure and the completed, in-service phase. The project will also provide criteria from which an efficient analysis of a curved composite system can be obtained using either commercially available software or approximate methods. An extensive data set documenting the behavior of composite steel girder systems within the I-99 Advanced Transportation Technology Test Bed will also be provided.

Real-Time Monitoring of Bridge Behavior via the Internet

Introduction/Background
The level of complexity for bridge inspections varies depending upon the size of the structure and on its past history. Typically, evaluations are performed visually using a crew of inspectors and mechanical and/or physical means of access. This approach is costly, time-consuming, and subjective. In addition, periodic inspections provide only a "snapshot" of the bridge condition which is unable to reflect changes in certain condition items (e.g. crack propagation, corrosion growth, etc.). Therefore, a non-invasive procedure that provides vital bridge condition information while lowering manpower and time requirements is of significant benefit to the bridge owner. Recent advances in instrumentation and computer acquisition systems, along with the growth of the Internet, make development of reliable automated bridge condition assessment systems feasible. The I-99 Advanced Transportation Technology Test Bed offers a rare opportunity to implement a prototype system during the construction of a bridge so that monitoring can occur throughout the structure's service life. It is proposed that one or more representative bridges (e.g. steel/concrete composite system, prestressed concrete system, etc.) be used as test structures for this project. Each bridge will be instrumented and "up-linked" to the Internet with the intent of developing an optimal methodology for instrumentation of bridges to provide (1) relevant "real-time" data at minimal cost; (2) a measure of the effectiveness of existing instruments (e.g. resistance and vibrating wire strain gages) against newer instruments (e.g. fiber optic sensors); and (3) a framework for presentation of pertinent information and "real-time" data on the Internet for bridges. In

addition, by-products of the project include the formation of a detailed history of each structure throughout its entire service life, comparison of actual full-scale behavior to predictions using current PennDOT analysis procedures, and comparisons of existing PennDOT design guidelines to observations of short- and long-term field behavior and to computer and laboratory models.

Approach

FIELD RESEARCH. Most of the tasks will be accomplished under this activity group, which encompasses all work completed while at the bridge site. The tasks include placement and activation of instrumentation (load/strain/deformation/acceleration, weather, video); placement and activation of acquisition and "up-link" systems; documentation of construction sequence; documentation of as-built structure; completion of controlled tests (i.e. static/crawl); completion of random tests (permit loads); and periodic visual inspection and instrument replacement.

COMPUTER RESEARCH. Computer research will be completed concurrently with the aforementioned activity groups. Work will focus on creation of analytical models and the Internet site. Task items associated with this activity include creation of a preliminary finite element model from the design plans; sensitivity studies of the finite element model; modification to the model from field measurements; comparisons between experimental and analytical behavioral predictions; and creation of and modification to an Internet "up-link" site.

Anticipated Results and Benefits

This project will demonstrate the viability of using the Internet and instrumentation to replace periodic field inspection for certain types of bridge structures. While it is not intended that automatic data acquisition schemes replace all visual inspections, certain instrumentation types and placement patterns will be recommended, which provide enough information on the health of a bridge structure to allow efficient planning of future management. It is anticipated that evaluation of the behavior of the bridges selected for this project will lead to some changes in current analysis and design philosophies. A framework for establishing automated condition systems for bridges within the Commonwealth will be developed, along with guidelines for selection and placement of instrumentation and acquisition systems.

Behavior of Slender Piers in Bridge Structures

Introduction/Background

Many slender pier columns have been designed using the moment magnifier method as described in the ACI 318 (1995) and the AASHTO Standard Specifications for Highway Bridges (1998) first presented by Breen and Macgregor. This method magnifies design moments produced from simple frame analysis to account for slenderness effects. Magnification factors are determined based upon applied end moments and axial forces and also on a critical load found using a reduced stiffness, which attempts to account for the effects of creep. While the moment magnifier method does provide viable *initial* design loads (moments and axial forces) that incorporate slenderness effects, no considerations for the age of the piers, outside of the creep factor involved in critical load calculations, are currently in place. As these piers age and experience deterioration, reexamination of their capacity is often required for load ratings and/or rehabilitation. If the moment magnifier method is used to determine loads in the piers, the effects of cracking or spalling in the cross section over time are not considered and changes in concrete properties are ignored.

The I-99 Advanced Transportation Technology Test Bed provides a unique opportunity to examine slender piers of various cross sections within a full-scale structure over their lifetime. These behavioral studies will provide valuable information so that the moment magnifier method can be modified for more realistic use in rehabilitation design. PennDOT can apply the modified approach to analyze deteriorated piers with greater accuracy, which will lessen the likelihood that unnecessary repairs take place, saving time and money. In addition to updating the moment magnifier method, various rehabilitation methods can be examined throughout the piers' lives and their effectiveness studied. It is proposed that slender concrete piers used for bridges be instrumented during construction and monitored throughout their service life. Results will be used to provide insight into short-and long-term behavior of slender piers; refine current stiffness modifications used within the moment magnifier method to better account for age and condition of the pier; propose modifications to the moment magnifier method for various pier cross sections, so that a better approximation of loads within them is obtained; and propose alternative methods for calculation of loads within slender piers.

Approach

FIELD RESEARCH. This activity group encompasses all work completed while at the bridge site. The tasks include documentation of construction sequence; documentation of as-built structure; placement and activation of instrumentation (load/strain/deformation); design and construction of coring blocks; completion of controlled tests (static/crawl); periodic visual inspection and instrument replacement; and construction of proposed rehabilitation schemes and monitoring of their effects.

COMPUTER/DESIGN RESEARCH. Computer and design research will be completed prior to and during the field and laboratory work. Penn State facilities and equipment will be used, and activities will center on the creation of analytical models and the completion of design calculations. Tasks involved include the creation of a preliminary finite element model from the design plans; sensitivity studies of the finite element model; modification to the model from field measurements; and comparisons between experimental, analytical, and design loads for as-built and rehabilitated piers.

Anticipated Results and Benefits
This project will develop modifications to current approximate methods for determining loads in slender piers when those piers are re-analyzed for load ratings or rehabilitation projects. Changes will be evaluated in (1) material properties over time, and (2) the column cross section due to deterioration affecting the behavior of slender piers. This project will also be used as a continual test site for various rehabilitation schemes and

will provide information as to the effectiveness of those schemes. This project will allow better characterization of conditions within the piers and will permit better-informed decisions regarding repair alternatives. This will, in turn, allow PennDOT to better use available manpower and materials, which will result in overall cost savings. In addition, a series of recommendations regarding the effectiveness of various pier rehabilitation schemes will be provided. The rehabilitation recommendations will be applicable to other slender piers within the Commonwealth and will reduce engineering design time.

WHITE PAPERS FOR I-99 CONFERENCE: TRAFFIC AND ITS

Lily Elefteriadou, Matt Lorenz, John Bagby, Elise Miller-Hooks, Martin Pietrucha, and Don Streit

Introduction

Traffic levels in the Centre region have constantly increased over the past several years, as the Centre region is the fastest-growing metropolitan area in Pennsylvania. In addition to the general increase of traffic, the scheduling of special events such as concerts, athletic events, and so on places is a strain on already congested highway facilities. On the other hand, upcoming infrastructure improvements (such as I-99, the Inner Loop, etc.) can provide unique opportunities to manage traffic growth using advanced technologies, and to optimize traffic operational quality.

This white paper outlines some transportation operational problems identified for the Centre region, along with potential solutions that could be implemented as part of the I-99 Advanced Transportation Technology Test Bed. Expected benefits with respect to safety and operational quality are also discussed.

<u>Identified Problems, Proposed Solutions and Expected Benefits</u>

1. Route Selection to Reduce Probability of Incident due to Adverse Weather Conditions

PROBLEM/OPPORTUNITY. Ice formation, slick roadway surfaces, low visibility, and other adverse weather conditions increase the likelihood of traffic incidents.

SOLUTION/RESPONSE. The use of real-time information concerning existing roadway conditions, as well as accurate forecasting techniques of future conditions, can be employed to select routes for motorists with reduced probability of incidents. A conceptual framework and algorithmic steps will be developed for determining optimal routes (i.e. routes with the minimum probability of incidents due to weather and roadway conditions) that exploit real-time and predicted information concerning dynamically varying and probabilistic roadway attributes (such as travel time and risk of incidents). The resulting techniques must fuse historical, real-time and predicted information obtained from surveillance and feedback mechanisms. These techniques can be used to direct and redirect vehicles, particularly vehicles carrying hazardous materials, in order to reduce the likelihood of an incident en route. Such a system can be employed along the I-99 corridor, including the surrounding roadway network, and should be incorporated within the overall traffic management plan for the region.

BENEFITS. Reductions in incident frequency and delay to motorists.

2. Emergency Response to Site of Hazardous Material Spills and Trauma Caused by Highway Accident

PROBLEM/OPPORTUNITY. In the event of a hazardous materials spill, trained personnel should be informed completely and quickly, and take immediate action using specialized equipment. Lack of appropriate information concerning the substance(s) involved, the magnitude of the incident, and the most rapid route to the spill site increase the chances of severe environmental damage resulting from the incident.

SOLUTION/RESPONSE. The advent and increasing deployment of mobile communication technologies has made it possible to provide emergency response units with real-time information concerning roadway incidents involving vehicles carrying hazardous substances and other highway accidents. Such information includes the type of substance the vehicle is carrying, the severity and exact location of the incident the best route to the incident; this information enables emergency responders to answer a hazardous situation quickly with the appropriate equipment and number of trained personnel. Decision-support technologies (including computer algorithms and analytical methodologies for real-time information processing, risk assessment, response action and route selection can be developed to reduce the impact of hazardous-materials spills along the I-99 corridor) utilize and integrate historical, real-time and predicted information on roadway conditions, travel times, and specific details of the incident or trauma into useful strategies and response instructions as required by the emergency response entities.

BENEFITS. Increased efficiency (i.e. reduced response and containment times) during response efforts to hazardous materials spills, and minimization of environmental damage.

3. Optimal Routing and Scheduling of Salting/Gritting and Snow Removal Vehicles

PROBLEM/OPPORTUNITY. Snow/ice management personnel currently lack access to real-time roadway conditions information. In addition, dynamic route optimization algorithms (used to direct salting/gritting and snow removal vehicles to priority locations most efficiently) are not used.

SOLUTION/RESPONSE. Through the use of advanced sensor technologies and other surveillance devices, estimates (or forecasts) of current (or future) snow levels and presence of ice on short stretches of roadway can be made. This information can be automatically relayed to a central computer to optimally route and schedule snowplows and salting/gritting vehicles given updated information on weather and roadway conditions. The conceptual framework and algorithmic steps can be developed for routing snowplows and salting/gritting vehicles along the I-99 corridor, using real-time information concerning dynamically varying roadway conditions and priority levels.

BENEFITS. Decreased operational costs and improved driver workload balance in day-to-day operations. Increased snow-clearing capabilities.

4. Signing Research Facility

PROBLEM/OPPORTUNITY. Development of new sign materials, sign alphabets, and electronic signs demonstrate that the highway signing system has not been fully optimized in terms of design. I-99 provides the opportunity for research, development, and full-scale implementation of static and active signing technologies.

SOLUTION/RESPONSE. A signing research facility could be developed, comprised of a two-story block house adjacent to the roadway with a single sign bridge and longitudinal, tracked ground mount for signs. The facility could be used to test various types of static and active signing (including CMS/VMS), sign illumination systems, sign materials, sign formats, etc.

BENEFITS. The facility provides a test-bed for research and development of active and static signing technologies, and provides grounds for full-scale implementation of state-of-the-art signing technologies.

5. Roadway Illumination Facility

PROBLEM/OPPORTUNITY. Highway lighting systems have been based on the concept of a single illumination source, single luminaire type, and single mounting position. Developments in computer control of mechanical systems would allow for a highway lighting system that responds in real time to changing ambient illumination and weather conditions. I-99 provides the opportunity for research, development, and full-scale implementation of roadway and interchange illumination technologies.

SOLUTION/RESPONSE. The roadway illumination facility would be used to test different types of roadway and interchange illumination. The facility would be composed of tracked gantrys that could be used to vary lateral and longitudinal placement, and height of luminaires. It could also be used to test different types of lighting systems (i.e., various types of bulbs, fiber optic, etc.). The systems could also be used to test vary types of "smart" lighting that varied with ambient lighting and weather conditions.

BENEFITS. The facility would provide a test bed for research and development of roadway and interchange illumination, and provide grounds for full-scale implementation of illumination technologies.

6. Precision Roadway Maintenance Facility

PROBLEM/OPPORTUNITY. Guiding maintenance vehicles to perform precise maintenance operations requires a highly skilled and experienced operator. Many maintenance activities require optimal lighting and weather conditions to proceed smoothly. Keeping snowplows on the paved roadway or allowing for line painting at night are examples of the types of problems that could be addressed. I-99 provides an opportunity for research, development, and full-scale implementation of automated guidance systems for maintenance vehicles.

SOLUTION/RESPONSE. The precision roadway maintenance facility would be used to explore the use of vehicle-guidance systems for maintenance functions. This facility might be used to study the guidance of winter maintenance vehicles (line painters, seal coaters, etc.) so that these operations proceed smoothly and precisely with minimal disruption to other traffic.

BENEFITS. The facility would provide a test bed for research and development of vehicle guidance systems, and provide grounds for full-scale implementation of these technologies.

7. Mayday System

PROBLEM/OPPORTUNITY. While mayday systems provide notification of an accident to a single dispatch location, notification of the appropriate response agencies is delayed until the nature of the incident is fully known.

SOLUTION/RESPONSE. A "smart" mayday system could be installed along the I-99 corridor. The system would have direct contact with PennDOT maintenance facilities, local police, fire, emergency medical services, and medical facilities.

BENEFITS. A smart mayday system would decrease response times and allow the appropriate response agencies to be notified of the nature of the incident.

8. Traffic Management and Parking for Special Events

PROBLEM/OPPORTUNITY. Athletic events, concerts, and other special events held at Beaver Stadium and the Bryce Jordan Center currently generate large volumes of traffic on the roadways in the vicinity of these two facilities. In addition to the increased demand, the presence of a large number of drivers who are not familiar with the State College area (nor the real-time availability of parking facilities), creates an additional strain on the highway network

SOLUTION/RESPONSE. Drivers, especially those unfamiliar with the area, should be properly guided to designated parking lots, avoiding areas of increased congestion. Real-time information regarding the availability of parking and current traffic conditions would reduce the delays experienced by drivers. Advanced technologies could be used to collect and disseminate such information along the I-99 corridor, as drivers approach the State College area.

BENEFITS. Reduced travel times and delay, and reduced probability of incidents during special events.

9. Integrated Traffic Signal Control System

PROBLEM/OPPORTUNITY. Currently, several different agencies operate and maintain the various traffic signal systems in the State College area. Because of this, many of the existing signal systems operate as independent entities uncoordinated with adjacent signal systems, resulting in an overall "piecemeal" signal network serving the area. Consequently, motorists currently experience undue delays and congestion levels at the jurisdictional boundaries between these systems.

SOLUTION/RESPONSE. The new I-99 facility creates a unique opportunity to address traffic signal control problems within the overall traffic management scheme for the region, including all interchange traffic signals. A state-of-the-art Traffic Management Center (TMC) would serve to integrate and coordinate the operation and maintenance of the various signal systems at a single location. Using state-of-the-art computer and communications technologies, the TMC would be enhanced through access to real-time traffic data, on-line control of individual signal displays, and incident detection and response capabilities.

BENEFITS. Reduction in overall operation and maintenance costs, reduced delays and stops for motorists, and reduced mobile emission levels.

10. Traveler Information Center

PROBLEM/OPPORTUNITY. Traveler information, provided by a variety of sources contains unreliable, conflicting, and contradictory messages that undermine and may defeat the purpose of providing information.

SOLUTION/RESPONSE. A real-time information clearinghouse (Traveler Information Center, TIC) should be created for the I-99 corridor; it would collect complementary and overlapping information, verify the validity of information, and broadcast messages to all travelers using different media of communication (e.g. the Internet, radio, variable message signs, 800 numbers, daily fax for a fee, etc.).

BENEFITS. Increased compliance with suggestions (e.g. traffic rerouting) decreased traveler costs, and an enhanced public relations profile.

11. Integrated Interactive Information System (INTERISYS) Ridesharing Program

PROBLEM/OPPORTUNITY. In transportation demand management ridesharing programs, two computationally intensive activities are ride matching and fleet management. Existing software and algorithms for these activities, which are at the heart of ridesharing success, solve the problem only partially.

SOLUTION/RESPONSE. The I-99 corridor is expected to be a major commuting facility. A pilot study is proposed that will produce a state-of-the-art ridesharing software using Geographic Information Systems (GIS), Differential Global Positioning Systems integrated with inertial navigation, and scheduling optimization software-Integrated Interactive Information System (INTERISYS).

BENEFITS. Lower costs in running a ridesharing program and higher customer satisfaction.

12. Advanced Weigh-In-Motion Data Collection

PROBLEM/OPPORTUNITY. Weigh-in-motion (WIM) systems can provide useful information for traffic statistics, weight-limit enforcement, and pavement-fatigue prediction. In the past, problems with WIM installation reliability have been a cause of concern for many highway engineers. The I-99 test bed is a unique opportunity to investigate WIM system reliability and the accuracy of data gathered by these systems, using a complete WIM installation.

SOLUTION/RESPONSE. The intent of this project is the installation and remote data acquisition of a complete WIM system. As a minimum, two rows of four LINEAS (quartz-based) sensors should be installed in both the driving and passing lanes. Included in this proposal is the installation of the LINEAS sensors, installation of the roadside enclosure for electronics, installation of all electronics and signal conditioning, and installation of electricity and telephone service to the WIM site. Electricity and telephone service are required to transmit data from the on-site computer to PennDOT and PTI facilities. Data from this system will include standard data such as vehicle classification, load for each heavy vehicle axle, and gross vehicle weight.

BENEFITS. A fully-functional WIM system using new and state-of-the art technology; remote data acquisition permitted by this system, providing a base for research and analysis for many years to come; experience and confidence with LINEAS WIM technology and associated data accuracy; a method by which tractor-trailers can selectively be chosen to enter a weigh station; and the ability to customize a data acquisition system to measure the dynamic loading applied to the pavement.

13. Capture and Use of Vehicle Data Recording Devices (Black Boxes) for Safety Management

PROBLEM/OPPORTUNITY. Vehicle manufacturers are increasingly installing and upgrading the capabilities of data recording devices (black boxes) in passenger vehicles. NHTSA is in the early stages of a multi-stakeholder consensus process likely to lead to a proposed rule making CVO data recorders mandatory. Both strong support and strong opposition are developing to the installation of black boxes. Particular concern is mounting regarding the variety of possible uses for the data captured, responsive highway maintenance, safety management, road design, vehicle design, litigation over product liability, and accident liability, as well as over loss of privacy and the communication and archiving methods employed for black box data.

SOLUTION/RESPONSE. The creation of an I-99 smart corridor would permit deployment of an ITS accident causation information capability. The capture of black box data would enable analysis of the data's accessibility and reliability and the efficacy of using such data to address numerous safety concerns (e.g., maintenance, highway design, vehicle design, and driver error).

BENEFITS. Establishing metrics for black box reliability; establishing guidelines for the capture, use and protection of data as black boxes proliferate and data-capture communication and archiving capabilities increase; and analyzing public-private sector cooperation in the implementation of ITS data systems that address safety issues.

WHITE PAPER FOR I-99 CONFERENCE: GEOTECHNICAL ENGINEERING PROJECT DESCRIPTIONS

Introduction

Penn State researchers have participated in lengthy discussions with Pennsylvania Department of Transportation (PennDOT) personnel from both District 2 and the Central Office, as well as with design consultants, regarding geotechnical issues related to the I-99 project. Several of these issues are problem areas that Penn State researchers are well qualified to address. Penn State researchers can significantly aid PennDOT in solving these problems for the construction of I-99 and for future transportation facilities.

Penn State is anxious to participate in this activity, both for the immediate opportunities it offers for engaging in technical activities on I-99, but also for the opportunity to develop a close, positive, and collaborative long-term relationship between Penn State technical experts and design professionals at PennDOT. It is to be hoped that the long-term relationship will to develop into a substantial level of technology transfer that includes technical expertise, research projects, and continuing professional education.

Site Investigation and Instrumentation

Problem Statement

Three of the significant geotechnical issues related to the I-99 project are as follows:

- Project areas with very low subgrade load-carrying capacity (CBR < 1). These areas could lead to substantial problems with the service life of the portland cement concrete pavements scheduled for I-99, particularly at the joints between adjacent pavement slabs where substantial differential movement could be generated under conditions of low subgrade support.

- Project areas that will require high embankments (> 100 feet) to be constructed on soft subgrade soils. Settlement of the embankment-supported roadway is a serious potential problem.

- Settlement of pavement slabs approaching bridges. This is considered a serious problem throughout the Commonwealth.

A geotechnical engineering issue is common and critical to the solution of these technical problems: the need to determine the stiffness (elastic) modulus of the in-situ and/or field-compacted soil materials on site. The elastic modulus is vital to the solution of settlement problems, yet it is not routinely measured by geotechnical engineering professionals, but inferred from parameters more readily obtainable. The correlations are typically very poor, and in the case of the bridge-approach-slab problem, the backfill material is often large stone, making the determination of the in-situ soil parameters seemingly impossible.

Research Approach

Penn State researchers are at the forefront of the technical community in the development and application of technologies for the determination of the elastic modulus of materials. At geotechnical engineering field sites, seismic wave propagation techniques are the preferred methodology. These methods can be conducted nondestructively from cased boreholes, or non-intrusively and nondestructively from the ground surface. In addition, they can be applied to virtually any soil type, including types that are typically difficult to penetrate with conventional sampling and testing techniques. Further, the methods are straightforward, economical, and are capable of being performed in a short period of time at a field site, and they have proven effective for a wide range of geotechnical engineering problems.

Penn State researchers are anxious to demonstrate the use of these proven methodologies on the settlement issues related to the I-99 construction. In particular, the researchers propose:

- Conducting surface wave propagation tests on the soft subgrade soils to assess their in-situ load-carrying capacity. An instrumentation system can subsequently be implemented to rationally assess the in-situ condition of the load transfer system at the pavement joints overlying these soft subgrade soils, following a procedure developed by Penn State during PennDOT Research Project 89-06. This system may prove to be very valuable for evaluation of jointed portland cement concrete pavements throughout the Commonwealth.

- Conducting surface-wave propagation tests on the soft subgrade soils underlying the high-embankment areas, and on the embankment soils during construction. These tests will provide in-situ modulus values for a rational assessment of the potential for settlement of these critical structures.

- Conducting borehole and/or surface wave propagation tests on the backfill materials underlying approach slabs to bridges. This backfill material is often large stone, and PennDOT engineers suggest that they currently are not able to confirm the adequacy of placement of these materials. Wave propagation methods will allow this assessment to occur. Placement problems can be identified and possible alternative backfill options may be investigated, including controlled low-strength fill materials.

Research Benefits

Penn State researchers anticipate great benefit to PennDOT as a result of these proposed activities. The geotechnical settlement problems are of serious consequence to the success of the I-99 facility and the research activities proposed herein have proven beneficial in many geotechnical projects worldwide. The activities will also provide an opportunity for Penn State to demonstrate to PennDOT the wide versatility that these techniques have for the assessment of civil engineering materials and infrastructure. The possibilities are endless.

Penn State Pile Capacity Model

Problem Statement

An accurate and relatively simple pile capacity model is an essential element required in pile foundation design. Although there are prediction models available, most are complex and difficult to use, and they require instrumentation on the pile, which interferes with the installation process. The Penn State model uses a simple pocket-size device to monitor pile driving far away from the pile. Therefore, the system does not affect pile installation and can monitor every pile. Field test data have indicated that the model is able to accurately predict pile capacity. However, before the model can be accepted for general use, it requires further validation and refinement under a broader range of conditions.

Research Approach

Data to be collected will include pile and hammer information, geotechnical data, and ground acceleration data induced by pile driving. Of these data, the pile and hammer information can be obtained from the contractor and PennDOT, the geotechnical data from the available results of subsurface investigations, and the ground acceleration data measured during pile driving.

The ground acceleration data will be reduced and analyzed using the theory of vibration to determine the pile capacity. The pile capacity will be compared statistically with the results obtained from wave equation analysis.

Research Benefits

The proposed research will produce a pile capacity prediction package that contains both hardware and software for use by PennDOT engineers. The prediction model will be simple to understand and easy to use, yet it can provide accurate prediction of pile capacity. The hardware system will be easy to operate and will not interfere with pile driving operations. Because the hardware system can monitor every pile, the quality of the entire pile foundation can be better assured.

APPENDIX B: TECHNICAL ISSUES

GEOTECHNICAL ENGINEERING WORKSHOP

Breakout Session I

The geotechnical engineering workshop produced the following problem statements during breakout sessions I and II:

1. How do we reconcile the actual material encountered on site during construction with the material assumed during design? Can the actual material sustain the structure loads?
2. Overdriven piles: can we assess the individual capacity of piles in the field?
3. Statistical assessment of site conditions.
4. Additional techniques for site investigation and characterization: the ability to develop a more comprehensive assessment of site conditions is needed.
5. Bridges on piles in karst terrain: more information is needed on site conditions, e.g., top of rock profile, void locations.
6. Compaction control: a better method to assess and control compaction of subgrades and embankments is required.
7. Is it beneficial to use geosynthetic separators between pavement sections and subgrades?
8. Pavement cracking near underground pipes.
9. Subgrade stabilization (e.g., geosynthetic, lime, other) versus undercutting.
10. Reinforced slopes: stability, reliability, economics.
11. Bridge scour: design calculations overestimate potential amounts of scour in rock due to poor criteria for assessing rock properties; rock is currently being excavated when it is in fact competent.
12. Bridge foundations: alternatives to piles, settlement of approach slabs, alternative abutment fill materials.
13. Available soils test data are often very limited, yet material parameters are required for design: a database of material parameters is required.
14. Bearing capacity estimates for rock appear extremely conservative.
15. Redirection of ground water following earth moving activities.
16. Soil (minimum of 3 feet) on top of rock embankments: is this a policy that should be altered or eliminated?
17. Cut/fill transition benches: standard detail is not available.
18. Should the earth loading behind a retaining wall or abutment be modeled with an inclined resultant? An inclined load significantly reduces the factor of safety with respect to bearing capacity.
19. Negative skin friction on piles: is it real, can coatings help eliminate it?
20. How do we estimate the unsupported length of battered piles?

Breakout Session II

In breakout session II, the problem statements were consolidated and summarily presented without rank in the lunch technical report as follows:

- Site investigation and characterization
- Approaches and foundations for bridges
- Settlement issues
- Lateral loads on structures
- Subgrade stability
- Compaction control
- Use of geosynthetics

HYDROSYSTEMS AND ENVIRONMENT WORKSHOP
Session I

The hydrosystems group, which met at the Penn State Conference Center Hotel, addressed two issues: identifying water-related problems that could or would result from the I-99 construction through Centre County, and reaching a consensus among the member of the group regarding what action items might be addressed in future research projects. In addressing the first issue a list of 15 potential problems were identified. There was a significant amount of overlap in the topics that were addressed in the afternoon session. The list of the problem areas developed in the morning session included:

1. **Instrumenting closed drainage systems for performance evaluations.** Culverts and French drains are two examples of closed system drainage systems whose performance is rarely assessed. A number of group members thought that it would be important to evaluate the performance of such closed systems to validate or improve on existing design methodologies.

2. **Seep wetlands hillslope hydrology.** When a highway embankment cuts across a watershed there are numerous cuts and fills; this is particularly true for the I-99 location along the ridge. Seeps are often either created by the cuts or eliminated by the fill material. This potential creation or elimination of wetlands has created a serious problem for PennDOT along portions of I-99 corridors. The U.S. Army Corps of Engineers, as well as the Pennsylvania Department of Environmental Protection (DEP), are very concerned with wetlands and the impact that construction can have on existing wetlands. For the first time, PennDOT was confronted with seeps as wetlands; an issue that was discussed was the creation of viable wetlands from cuts along the highway corridor.

3. **Evaluation of wetland design effectiveness.** How well do constructed wetlands function? At the present time there is little quantitative criteria to evaluate the design and construction of wetlands. It would be helpful to PennDOT to have a tool that it could use as it develops mitigation practices for replacing existing wetlands.

4. **Stream restoration.**
   a. The development of regional curves
   b. Problems with sediment transport
   c. Evaluation of restoration practices at bridges and culverts
   d. Evaluation of enhancements to the stream system

   There are approximately 20,000 feet of waterways that will have some type of stream restoration practice. Much work must be done to assess these practices.

5. **Microclimate modeling.**
   a. Microclimates themselves: Does the location of I-99 along the ridge create any adverse microclimates?
   b. Does the corridor along I-99 create adverse wind conditions (e.g., does the terrain along the ridge create an adverse wind tunneling effect?)?

There are several interstate highway corridors in Pennsylvania that create adverse terrain-generated wind along the highway right-of-way; Cresson Mountain is a prime example. Because of the I–99 location, there is some concern that high winds could be generated that will affect safety of highway motorists.

6. **Impacts of maintenance and operations of deicing and herbicides on water quality**. PennDOT utilizes a deicing substances and herbicides along the right-of-way. What is the potential hazard from these practices along the waterway conveyance systems?

7. **Erosion and deposition at bridges and culverts**. Any bridge or culvert is susceptible to erosion and/or deposition. Are there any potential problems along the I-99 corridor for new bridges and culverts?

8. **Hydrologic modeling for water quantity and quality of surface and subsurface flows**. PennDOT is required by several federal and state agencies to monitor both water quantity and quality for conveyance systems that could be altered by a highway corridor. The duration of the monitoring can be as much as ten years. If a hydrologic model could be calibrated and proven to predict reasonably well, it would reduce the required monitoring by as much as 50 percent.

9. **Subsurface pavement drainage**. Where does the drainage go? What is the water quality of the drainage water and does it adversely impact ecosystems?

10. **Observation of failures and successes along the I-99 corridor as well as on other PennDOT projects**. Similar to a literature review.

11. **Drainage management**. Along the headwaters of South Bald Eagle Creek, PennDOT has designed a complex water collection system that isolates the intercepted groundwater; pavement water, and the natural watershed overland flow.

12. **Water quality impacts of highway drainage**. This problem concerns both surface and subsurface water. In one location along I-99, PennDOT is separating the highway drainage, the subsurface drainage, and the natural watershed runoff drainage and handling them differently. The highway drainage–at least the first one-inch of runoff–will be treated in detention basins located along the highway corridor. An evaluation of these procedures would be in order.

13. **Instrumentation and monitoring (across all groups).**

14. **Culverts, culvert materials, and shapes**. A few culverts will be located along steep portions of the cross drains. What can be done with culvert material, size, and shape to help alleviate some of the adverse effects of high velocity streams?

15. **Drainage through recycled materials water quality issues.**

MATERIALS AND CONSTRUCTION WORKSHOP

Session 1

Needs

Session 1 focused on defining the needs of highway infrastructure with regards to materials and construction. PennDOT personnel, contractors, material suppliers, and other participants presented the following 23 needs:

1. Concrete pavements are cracking after only a few years of service and at less than half of the design ESALs. This is believed to be related to one or more of the following parameters:

    a. Sub-base materials problems–OGS / evaluations.
    b. Geotechnical site-specific factors.
    c. Methodologies for compaction.
    d. Compaction control.
    e. Procedures used in evaluation (in-situ).
    f. Built-in stresses from temperature differential problems.

2. Concrete bridge decks are exhibiting cracking in the first few weeks and in the first year. There are continued problems with mixture designs and measuring performance. The following are contributing factors:

    a. The common misconception that "more strength is better."
    b. High early strength obtained from AAA mixtures.
    c. Curing procedures for decks that are insufficient and not enforced.
    d. Criteria such as minimum sack content and maximum w/cm ratio that do not optimize properties.
    e. A lack of measures for durability performance in PennDOT specifications other than strength; high-strength concrete does not necessarily equal high-performance concrete..
    f. A permeability to chloride that is too high, but not required by specification.
    g. Decks that may be routinely overheating from rapid hydration.
    h. The need for durability to be at the forefront of specifications.
    i. The possible presence of retarders in 90 percent of mixture designs for AAA concrete. While it is understood that the retarder is not always used, this is still a high percentage of routine retarder usage.

3. PennDOT does not consider factors related to durability for pavements or bridges. There is a need to define what tests can be specified and used during construction and for inspections after construction.

4. Chloride-based deicing materials are a major contributing factor to bridge and pavement joint deterioration. We need to understand the type, impact, and amounts of deicing materials used.

5. There is a need to accelerate project times to decrease driver delay. This is especially true in urban areas and on high traffic corridors. Rapid-strength materials that are durable under loading are also needed.

6. There is a need for more durable bridge decks. The designer of bridge decks needs guidance on the following considerations:

   a. Rebar type
   b. Permeability
   c. Shrinkage Control
   d. Maturity
   e. Salt Concentrations
   f. Cathodic Protection
   g. Curing Procedures

7. The cost of new bridges should benefit from high-strength concrete technology. Bridge designers need the option of using greater than 8 ksi concrete for the following reasons:

   a. HPC Girders
   b. Longer spans
   c. Less substructure
   d. Lighter weight
   e. Less girders
   f. Aesthetics/Maintenance
   g. Better Public Opinion
   h. Reduced Annual Costs
   i. Inspectability

8. The commitment to using of glass, tires, foundry sands, fly ash, slags, shingle tabs, and other recycled materials with good engineering properties is a positive step. However, guidelines for the use of recycled materials are needed, especially for the following:

   a. Embankments
   b. Base material
   c. Drainage course

9. Evaluating on-site materials is a continued problem. There is no protocol for determining if a material should be disposed of or stabilized.

10. Plowable raised pavement markers and extended-life reflective lane stripes are needed. The markers and paint stripes currently in use do not retain their reflectivity index for more than a winter, even if the markers and paint stays in place.

11. SHRP snow fence technology should be implemented in areas of drifting snow. Both natural and manmade snow fences should be considered.

12. Low-maintenance vegetation for roadsides could greatly decrease the funds spent on routine.

13. Pavement joints continue to be problem. The current design considerations for joint seals, dowel placement, depth of joint cut, and joint spacing should be revised.

14. The inconsistency between ASD and LRFD in foundation design should be resolved. The resistance factors for soils and steel and concrete are not consistent in the design procedure.

15. Pavement designers need a better evaluation of HPC, Superpave, and ordinary concrete pavement to determine which is better for different applications. The model should consider the following:

    a. Life-cycle cost models
    b. Time considerations w/ rigid pavements–flexible pavements are built more quickly and cheaply require repaving in the future.
    c. Vehicle loadings and volume

16. Optimization of pavements contracts to reduce construction time and claims costs. The problem should consider the effects of the following:
    a. Linear scheduling
    b. Monitoring practices for CPM
    c. Scheduling to potentially solve problems

17. Double-lift paving or roller compacted pavements should be considered to optimize the use of high quality material on the top lift, and the use of recycled materials and more inexpensive mixtures on lower lifts.

18. There is a need to review contract administration plus bidding plus scheduling for highway projects. Project management could accelerate contracts by as much as 15 percent if different tools were put in place.

19. Bridge approach slabs have settlement problems. These settlements lead to unintended longitudinal loadings on bridges, vertical oscillations in trucks, and ride problems. The compaction and backfill materials and procedure may be inadequate.

20. Studies on the success on right-of-way relocations are needed. It is unclear whether persons relocated by the highway infrastructure have successful transitioned into a new location and life.

21. Sound-abatement techniques should be looked at more closely, particularly the use of Jersey barriers and recycled materials-based walls.

22. The department needs performance-based specifications for vegetation as well cover soils.

23. Pavement and bridge performance data are needed to properly evaluate the design decisions of engineers. Studies should consider a variety of instrumented bridges and pavements for cracking, stresses and thermal cycles.

Session 2

Major Focus Areas

Session 2 activities grouped the needs/problem statements from session 1 into six focus areas and provided performance objectives for each area to guide the development of research approaches or problem solutions. The six areas are presented below with the performance objectives and related needs/problem statements.

1. Durability of Bridges and Structures (Decks, Superstructure, Substructure, Walls, Barriers, Culverts).

   Guiding performance objectives

   - 50-year Performance Life
   - 20-year Maintenance Free
   - Need Performance Index

   Related needs/Problem statements

   - (#2) Concrete bridge decks are exhibiting cracking in the first few weeks and in the first year. There are continued problems with mixture designs and measuring performance.

   - (#3) PennDOT does not consider factors related to durability for pavements or bridges. There is a need to define what tests can be specified and used during construction and for inspections after construction.

   - (#4) Chloride-based deicing materials are a major contributing factor to bridge and pavement joint deterioration. We need to understand the type, impact, and amounts of deicing materials used

- (#6) There is a need for more durable bridge decks.

- (#7) The cost of new bridges should benefit from high-strength concrete technology. Bridge designer need to have the option to use greater than 8 ksi concrete.

- (#23) Pavement and Bridge performance data is needed to properly evaluate the design decisions of engineers. This should consider a variety of instrumented bridges and pavements for cracking, stresses and thermal cycles.

2. Pavement Design Life Issues (Life Cycle, Acceleration, Joints, Bases).

Guiding performance objectives

- 50-Year Performance Life
- 20-Year Maintenance Free
- Need Performance Index

Related needs/Problem statements

- (#1) Concrete pavements are cracking after only a few years of service and at less than half of the design ESALs.

- (#3) PennDOT does not consider factors related to durability for pavements or bridges. There is a need to define what tests can be specified and used during construction and for inspections after construction.

- (#4) Chloride-based deicing materials are a major contributing factor to bridge and pavement joint deterioration. We need to understand the type, impact and amounts of deicing materials used.

- (#5) There is a need to accelerate project times to decrease driver delay. This is especially true in urban areas and on high traffic corridors. Rapid-strength materials that are durable under loading are needed.

- (#13) Pavement joints continue to be problem. The current design considerations for joint seals, dowel placement, depth of joint cut, and joint spacing should be revised.

- (#15) Pavement designers need a better evaluation of HPC, Superpave, and ordinary concrete pavement to determine which is better for different applications.

- (#17) Double-lift paving or roller compacted pavements should be considered to optimize the use of high quality material on the top lift, and the use of recycled materials and more inexpensive mixtures on lower lifts.

- (#23) Pavement and bridge performance data is needed to properly evaluate the design decisions of engineers. This should consider a variety of instrumented bridges and pavements for cracking, stresses, and thermal cycles.

3. Contract Administration (Time-Line Impact, performance based specifications, innovative Contracting)

   Guiding performance objectives

   - Reduction of time by 15 percent

   Related needs/Problem statements

   - (#16) Optimization of pavements contracts to reduce construction time and claims costs.

   - (#18) There is a need to review contract administration + bidding + scheduling for highway projects. Project management could accelerate contracts by as much as 15 percent if the different tools were put in place.

   - (#20) Studies on the success on right of way relocations are needed. It is unclear whether those persons relocated by the highway infrastructure have successful transitioned into a new location and life.

4. Maintenance (anti-icing, markers /striping, anti-graffiti)

   Guiding performance objectives

   - 4-year maintenance cycles for marker and stripes and similar items

   - More cost-effective solutions

   Related needs/Problem statements

   - (#10) Plowable raised pavement markers and extended life reflective lane stripes are needed. The markers and paint stripes currently in use do not retain their reflectivity index for more than a winter, even if the markers and paint stay in place.

   - (#11) SHRP snow fence technology should be implemented in areas of drifting snow. Both natural and manmade snow fences should be considered

   - (#12) Low-maintenance vegetation for roadsides could greatly decrease the funds spent on these routine items.

- (#21) Sound-abatement techniques should be looked at more closely, particularly the use of Jersey barriers and recycled materials-based walls.

- (#22) The department needs performance-based specifications for vegetation as well as cover soils.

5. Subgrade/Subbase (amendments, stabilization, approach slabs, in-situ testing, compaction control, settlement embankments)

   Guiding performance objective
   - Performance base and method of evaluation

   Related needs/Problem statements
   - (#9) Evaluating on-site materials is a continued problem. There is no protocol for determining if materials should be disposed of or stabilized.

   - (#14) The inconsistency between ASD and LRFD in foundation design should be fixed. The resistance factors for soils and steel and concrete are not consistent in the design procedure.

   - (#19) Bridge approach slabs have settlement problems, which lead to unintended longitudinal loadings on bridges, vertical oscillations in trucks and ride problems. The compaction and backfill materials and procedure may be inadequate.

6. Recycled and Byproducts (Glass, Tires, Fly Ash, GGBFS, Rubberized Concrete, Shingle Tabs)

   Guiding performance objectives
   - Determine optimum use and consume stockpiles in Pennsylvania.

   Related needs/Problem statements
   - (#8) The commitment to using of glass, tires, foundry sands, fly ash, slags, shingle tabs, and other recycled materials with good engineering properties is a positive step. However, guidelines for the use of recycled materials are needed.

   - (#17) Double-lift paving or roller-compacted pavements should be considered to optimize the use of high quality material on the top lift, and the use of recycled materials and more inexpensive mixtures on lower lifts.

   - (#21) Sound-abatement techniques should be looked at more closely, particularly the use of Jersey barriers and recycled materials-based walls.

STRUCTURES WORKSHOP

Breakout Session I and II

Summary

Consolidation of certain problem statements

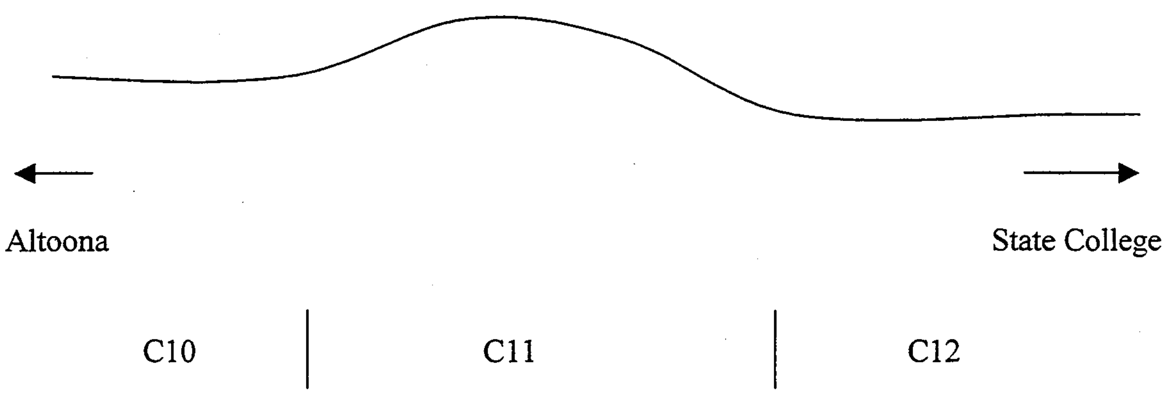
- Contractor influence of fabrication modification, movement of structures (curved and skewed bridges), and beam spacing on skewed bridges.
- Use of wireless communications (reliability, power source) and reliability of embedding sensors.
- Culverts under high-fill and precast box culvert compared to CIP and long term performance.
- Deck cracking, effect of added surface water.

Refinement of all of the problem statements

- Inability to accurately predict movement and stresses in curved and skewed structures during construction and service.
- Lack of accurate strength prediction for curved steel girders within composite systems.
- Need to assess long term viability of MSE walls.
- Need to more accurately predict transfer length of prestressing strands.
- No established method for predicting movement and stresses in integral abutments.
- Need to reassess design criteria for plain elastomeric bearings, in terms of performance, construction, and capacity.
- Inaccurate design methodology for culverts under high fill.
- Current seismic design standards require highly congested rebar. Is this really necessary?
- Long-term stiffness loss of slender bridge piers is unknown.
- Inability to consistently prevent deck cracking.
- Need to understand the requirements of embedded sensors in relation to power sources and communication.
- What are the effects of creep on prestressed beams, and the consequential effect of creep on camber and grade, in the short term (first six months)?
- Reinforcement corrosion due to chloride intrusion.
- Current technology limits span lengths for prestressed beams.
- Expansion joints perform poorly in the long term.
- Bridge approach slab movement must be stopped.
- Unknown transfer of forces through horizontal joints for precast substructure elements.

RIGID PAVEMENT PERFORMANCE WORKSHOP

Sessions I and II: Problem Generation and Consolidation Sessions
The workshop began with a discussion of the layout of the 18-mile I-99 construction sections. The pavement has been designed in three subsections, with multiple construction contracts for some of the sections. The pavement designs and probable contract let dates were discussed, as these factors affect the feasibility of addressing some research issues. The design sections and corresponding planned pavement designs are illustrated schematically and tabulated below.



	C10	C11	C12
Thickness of Slab (inch)	10	11	11
Thickness of Base (inch)	4	4	4
Thickness of Subbase (inch)	6	6	6
Number of Contractors	2	2	3

The morning workshops continued with the brainstorming and discussion of many issues. The group strongly opined that opportunities for improvement should be emphasized rather than problems. Approximately 43 ideas were noted during the initial session.

During the second session, the issues and opportunity areas were categorized into six groups. They were summarized and placed into groups as follows:

Monitoring and Evaluation

- Selection and installation of sensors
- Joint movement
- Subbase drainage efficiency
- Traffic
- Weather monitoring system
- Roughness
- Triggers for maintenance, rehabilitation, and strengthening

- In-place LCCA comparisons
- Seasonal monitoring of subgrades (Moisture, Frost, FWD)
- Permanent monumentation of test section
- Instrumentation plan

Truck-Pavement System Interaction

- Characterization of pavement system interaction
- Axle spacing and suspension system
- Regular profile measurements
- Profile measurements in conjunction with temperature
- Design for rumble strip
- Run instrumentation on highway to analyze wheel loads at specific time intervals (monthly) to determine the best time for maintenance activities
- Measure variability throughout project (FWD) at 1-meter intervals
- Define static and dynamic loading; correlate to pavement roughness and joint spacing
- Correlate causes and effects
- Measure total pavement system response

Subbases

- OGS gradation variation
- OGS vs. permeable treated base
- Geotextile/subgrade separation layer
- Various treated subbases
- FWD to look at uniformity of subgrade
- Adequate characterization of subbase
- Design beyond minimum–vary thickness
- Install different gradations and thicknesses of subbase
- Daylighting subbase
- Design for frost

Concrete Mix Design

- Optimization of Flexural Strength
- Manufactured sand in shoulder
- Specify a lab flexural strength on a test section and let contractor do mix design
- Investigate durability of different mix designs
- Manufactured sand under shoulders
- Accelerated concrete

Pavement Design

- Joint spacing
- Variation in longitudinal joint tie bars
- Widened lanes and shoulder design
- Pressure relief joints
- Evaluation of performance of joint design practices
  - Transverse joints
  - Longitudinal joints
- Implement cost optimization
- Evaluation of noise and skid friction vs. surface texture
- Diamond grinding

Construction Issues

- Multiple sources of materials
- Evaluation of the construction parameters and their effects on pavement performance–variability in material characteristics and their effects on pavement performance
- Development of performance criteria and comparison between the criteria and the product.
- Utilize FHWA mobile concrete lab
- Document construction practices, materials, and inspection
- Innovative bidding and/or contract procedures
- Review bonus/penalty criteria
- Curing method
- Managing multiple contractors
- Manufactured sand in shoulder
- Multiple material sources
- Two-lift construction

TRAFFIC AND ITS WORKSHOP

This memorandum summarizes the proceedings of the "Traffic and ITS" technical area. This document describes the consensus-building procedure and conclusions reached throughout the day during each of the four breakout sessions.

Breakout Session I

General and specific problem areas—as well as areas of opportunity—were solicited from the participants. The identified problem and opportunity areas (including those originally identified as part of the "Traffic and ITS" white paper) are listed below, along with a short description of each.

- ***Driver advisories during adverse weather conditions.***
  During adverse weather conditions, the use of real-time information concerning existing roadway conditions, as well as accurate forecasting techniques of future conditions, can be employed to select routes for motorists with reduced probability of incidents. This system should be combined and interconnected to a larger system of highway advisories.

- ***Emergency response to hazardous material spills***
  Mobile communication technologies provide emergency response units with real-time information concerning roadway incidents involving vehicles carrying hazardous substances and other highway accidents. This information results in decreased response times and increased efficiency during spill containment and incident management phases.

- ***Routing and scheduling algorithms for salting/gritting and snow removal vehicles.***
  Advanced sensor technologies and other surveillance devices allow for estimation (or forecasting) of current (or future) snow levels and the presence of ice on short stretches of roadway. This information is automatically relayed to a central computer that determines how to optimally route and schedule snowplows and salting/gritting vehicles.

- ***Optimization of highway signing design.***
  I-99 provides an opportunity for research, development, and full-scale implementation of static and active signing technologies. A signing research facility, along with a single sign bridge and longitudinal tracked ground mount for signs, could be developed to test various types of static and active signing (including CMS/VMS), sign illumination systems, sign materials, sign formats, etc.

- ***"Smart" highway illumination***
  I-99 provides an opportunity for research, development, and full-scale implementation of roadway and interchange illumination technologies. A roadway illumination facility could be developed to test different types of roadway and interchange illumination. The facility could be composed of tracked gantrys that

could be used to vary lateral and longitudinal placement and height of luminaires. It could also be used to test different types of lighting systems (i.e., various types of bulbs, fiber optic, etc.). In addition, the systems could be used to test various types of "smart" lighting that vary with ambient lighting and weather conditions.

- ***Automated guidance for maintenance vehicles***
  I-99 provides an opportunity for research, development, and full-scale implementation of automated guidance systems for maintenance vehicles. The precision roadway maintenance facility could be used to explore the use of vehicle guidance systems for maintenance functions. The facility provides a test bed for research and development of vehicle guidance systems, and provides grounds for full-scale implementation of these technologies.

- ***Incident response***
  A "smart" mayday system could be installed along the I-99 corridor. The system would have direct contact with PennDOT maintenance facilities, local police, fire, emergency medical services, and medical facilities, resulting in decreased response times and allowing the appropriate response agencies to be notified of the nature of the incident. GPS and communications technology (such as cellular technology) could be utilized.

- ***Traffic management and parking during special events***
  Drivers, especially those unfamiliar with the area, need to be properly guided to designated parking lots, avoiding areas of increased congestion, during special events at Beaver Stadium and the Bryce Jordan Center. Real-time information regarding the availability of parking and current traffic conditions will reduce the delays and travel times experienced by drivers. Advanced technologies can be used to collect and disseminate such information along the I-99 corridor, as drivers approach the State College area.

- ***Integrated traffic signal control system***
  The presence of the new I-99 facility creates a unique opportunity to address traffic signal control problems within the overall traffic-management scheme for the region, including all interchange traffic signals. A state-of-the-art Traffic Management Center (TMC) would serve to integrate and coordinate the operation and maintenance of the various signal systems at a single location. Using state-of-the-art computer and communications technologies, the TMC would be enhanced through access to real-time traffic data, on-line control of individual signal displays, and incident detection and response capabilities, resulting in a reduction in overall operation and maintenance costs, delays and stops for motorists, and mobile emission levels.

- ***Traveler information center***
  A real-time information clearinghouse (Traveler Information Center [TIC]) could be created for the I-99 corridor to collect complementary and overlapping information, verify the validity of that information, and broadcast messages to all travelers using different communication media.

- ***Ride matching and fleet management software***
  The I-99 corridor is expected to be a major commuting facility. A pilot study is proposed that will produce a state-of-the-art ridesharing software using Geographic Information Systems (GIS), Differential Global Positioning Systems integrated with inertial navigation, and scheduling optimization software (Integrated Interactive Information System, [INTERISYS]).

- ***Weigh-in-motion data***
  Weigh-in-motion (WIM) systems can provide useful information for traffic statistics, weight-limit enforcement, and pavement-fatigue prediction. In the past, problems with WIM installation reliability have been a cause of concern for many highway engineers. The I-99 test bed is a unique opportunity to investigate WIM system reliability and the accuracy of data gathered by these systems, using a complete WIM installation.

- ***Guidelines for "black box" use in passenger vehicles***
  The creation of an I-99 smart corridor would permit deployment of an ITS accident causation information capability. The capture of black box data would enable analysis of the data's accessibility and reliability and the efficacy of using such data to address numerous safety concerns (e.g., maintenance, highway design, vehicle design, driver error). Tire pressures may be monitored using the black box technology as well (see *Monitoring of Tire Loads on Pavement* below).

- ***Pre-clearance commercial vehicle operations monitoring***
  Commercial vehicles are inspected at roadside rest stops. This technology is currently being tested.

- ***Monitoring of tire loads on pavement***
  This system permits tire pressure on the inside and outside tires of heavy vehicles to be monitored. The data can be used to estimate pavement life for maintenance purposes, and/or enforce vehicle load limits.

- ***On-board vehicle rollover technology***
  This system would enable drivers of heavy vehicles to receive information (precautions, warnings and alarms) from the highway infrastructure regarding curve geometry in order to avoid vehicle rollovers.

- ***Regional bus service and information systems***
  HOV and/or bus priority changes in regional transit patterns.

- ***Safety implications of wireless 911 geo-location technology***
  Wireless, cellular and PCS telecommunications proliferate in vehicles. With the introduction of digital and PCS derivations of these services/devices, it is possible to identify the location of vehicles using such services with much greater precision. Location referencing has numerous safety, law enforcement, privacy, and commercial

applications. Such data can be correlated with GPS, black box, and other traffic-related data to optimize safety, law enforcement, and traffic management incidents and conditions.

- ***Automated enforcement screening technologies***
  Using advanced technologies are used for enforcement to minimize traffic violations.

- ***Driver information for interchange services***
  This system would provide drivers with information regarding services provided at interchanges along the I-99 corridor, including the locations of restaurants, hotels, gas stations, and other related traveler services. Low-frequency radio was suggested as an applicable technology for this project.

Breakout Session II

The second session consisted of assigning each of the problem and opportunity areas identified during the first session to one of six "general problem categories." A few of the problem and opportunity areas identified during the first session were modified, reworded, and/or combined with other areas. The six general problem categories correspond to those identified under the national ITS architecture are listed below, along with the associated problem statements from the first session.

General Problem Categories:

1. Maintenance / Facility Management
   - Routing and scheduling algorithms for salting /gritting and snow removal vehicles
   - Automated guidance for maintenance vehicles
   - Monitoring of tire loads on pavement (weigh-in-motion for maintenance)

2. Incident Management and Emergency Response
   - Emergency response to hazardous material spills
   - Incident prediction, detection, and classification
   - Incident response

3. Traveler Information
   - Driver advisories during adverse weather conditions
   - Optimization of highway signing design
   - "Smart" highway illumination
   - Driver information during special events
   - Driver information for food and lodging services

4. Commercial Vehicle Operations
   - "Black Box" use in all vehicles
   - Pre-clearance commercial vehicle operations monitoring
   - On-board vehicle rollover technology
   - Automated enforcement screening technologies

- Commercial vehicle driver information

5. Public Transportation
    - Ride matching and fleet management software
    - Regional bus service and information system

6. Traffic Management
    - Special events
    - Signal systems coordination
    - Automated enforcement screening technologies
    - Recurring congestion

FLEXIBLE PAVEMENT PERFORMANCE: SPECIAL MEETING MINUTES, JULY 28, 1999

A meeting to develop Superpave-related research and demonstration projects was conducted at the Penn State Conference Center Hotel on July 28, 1999. The meeting was organized and led by Dr. David A. Anderson. Participants included representatives from PennDOT districts and the central office, the FHWA, industry, and Penn State.

To provide relevant background to all participants, the meeting began with an overview and update on related activities. Gary Hoffman's introductory remarks indicated that PennDOT was committed to revitalizing the test track facility in the context of the need for Superpave validation. In addition, there are several full-depth asphalt concrete sites planned close to Penn State. Mr. Hoffman said that the states have to take more responsibilities as a consequence of the cut in funding for FHWA, and that he was looking for quality ideas from the present group.

David Anderson presented past pavement-durability (test track) activities and the need for a new research cycle at the pavement durability facility. Various scenarios for upgrading the existing facility were discussed, along with the associated costs.

Tim Ramirez presented the status of PennDOT Superpave implementation. After September 2000, all asphalt concrete jobs in Pennsylvania are targeted to be Superpave. Next year, 65 percent of the newly built pavements will be Superpave, ranking PennDOT in the first 25 state transportation agencies in the country. There are at least ten projects appropriate to use for validation studies.

John D'Angelo presented the latest Superpave validation efforts at the national level, including the WesTrack facility, the Superpave performance model contract, and relevant NCHRP projects. Terry Mitchell presented an overview of accelerated pavement testing facilities. He talked about WesTrack, MnRoad, the new track under construction at Auburn, and the Penn State facility.

The meeting continued with active and participatory discussions about research needs that could be addressed by use of the pavement durability facility, or through field and laboratory studies. Two areas of vital importance are asset management and life-cycle costs. In order to manage the pavement infrastructure efficiently, and to make realistic and balanced decisions, improved inputs to these processes are required. Better and updated predictions of treatment lives and maintenance needs, and validated design procedures are necessary.

It was agreed that appropriate instrumentation would be vital to any research undertaken. Instrumentation should include the pavement, traffic, and weather. It was suggested that instrumentation be placed on some full-depth asphalt concrete projects being constructed in the field in the current or next year's construction season.

The evaluation of Superpave within the integrated context of overall pavement design, with comparable attention to all components, was the central point of a significant discussion. The importance of truck-pavement system interaction, and the utilization of an instrumented truck to understand loading characteristics, was discussed as part of the system. Roughness affects pavement life, due to increased dynamic loads with increased roughness.

Research needs were discussed for all pavement components. Some urgent materials-related research needs include:

- The use of either stiffer or softer asphalt binder in lower pavement layers,
- An evaluation of binders produced by different means but to the same performance grade,
- The use of RAP in Superpave mixes,
- The benefits and costs of SMA versus Superpave performance,
- The influence of aggregate characteristics on pavement performance, particularly regional characteristics,
- The relative performance of different top-size mixes,
- Subbase improvements, and
- Subgrade improvement, indications and techniques.

The mechanistic design procedures that are expected in the new AASHTO guide will require validation. The predominant distress types in Pennsylvania were discussed; participants agreed that opening of longitudinal joints was the first distress to appear in Superpave pavements.

The need for regional climate-specific Superpave validation was highlighted. Concern about moisture damage and freeze-thaw effects on the pavement structure, and the interaction with drainage was expressed. The effectiveness of AASHTO T-283, wheel-tracking tests, and other current tests was discussed; there is a need to examine the mechanisms of moisture damage and effects of construction parameters.

Potential Superpave overlay performance studies were considered. The placement and evaluation of an overlay on a poor-draining pavement, including study of the best-performing materials for that application, was suggested. A field study on techniques, use, and design of thin overlay mixes was also suggested. Concern was expressed regarding reflective cracking; overlay applications represent a major use of Superpave mixtures in Pennsylvania, thus warranting laboratory and field studies. The need to incorporate an evaluation of constructibility at the design phase and to achieve quality construction was discussed. Construction-related research needs include:

- Unpredictable difficulty in achieving density (perhaps due to a tender zone, compaction temperature, more and/or bigger rollers, aggregate crushing, or moisture),
- Accurate density measurements for porous mixtures,
- An examination of construction parameters and equipment to achieve density,
- Relationship of density to performance, and a

- Strength test for quality control.

It was concluded that there was an immediate need for research efforts to address the issues identified at the meeting. This effort should combine the unique advantages of test track research (controlled traffic and conditions) with the immediate advantages of test sites in new construction areas (ready to use, a multitude of factors that could be screened for importance for further test track evaluation). The discussions also emphasized the leadership role played by NECEPT as an organization that "shows direction to the community."

APPENDIX C: RESEARCH ACTIONS

GEOTECHNICAL ENGINEERING

Breakout Session IV

In breakout session IV, a prioritized list of action areas was developed from the highest ranked problem statements from session III. Each person was asked to list his or her top three action areas from among the list of highest ranked statements. A total number of ranking points was then calculated for each statement, using a weighting system: 3 points for a first-place vote, 2 points for a second-place vote, and 1 point for a third-place vote. This ranking produced:

Statement Number	Statement Title	No. of 1st-Place Votes	No. of 2nd-Place Votes	No. of 3rd-Place Votes	Total Points
#4	Site Assessment				
#9	Subgrade Stab.				
#19	Skin Friction	2	2	2	12
#6	Compaction Control	1	1	3	8
#12	Approach Slabs	0	1	3	5
#2	Overdriven Piles	1	1	0	5
#14	Rock Properties	0	0	1	1

From the ranking shown above, a prioritized list of action areas for geotechnical engineering was presented in the final plenary session as follows:

1. Techniques for site characterization
2. Subgrade stabilization
3. Negative skin friction
4. Compaction control
5. Approach slab settlement
6. Pile capacity prediction
7. Over-conservative rock properties

Funding

The geotechnical engineering group at Penn State is capable and eager to work with PennDOT personnel in developing specific project tasks for the I-99 facility with the aim of providing solutions to the high priority action items listed above. It is anticipated that a combined research effort will require approximately $300,000 per year over a five-year period as follows:

2 faculty @ $50,000/faculty:	$100,000

5 graduate students/technicians @ $30,000/person:	$150,000
Outside testing services, equipment, etc.:	$50,000
Total annual requirement:	$300,000

Integrated Facilities for Testing and Research

The geotechnical engineering group at Penn State anticipates the need for additional infrastructure and testing equipment for participating in the I-99 research as follows:

Electro-dynamic shaker:	$15,000
Hewlett Packard data acquisition upgrade module:	$10,000
Crosshole seismic testing equipment:	$10,000
Miscellaneous electronic transducers, signal conditioners, etc.:	$15,000
Total:	$50,000

HYDROSYSTEMS AND ENVIRONMENTAL WORKSHOP

Sessions III and IV

The purpose of the afternoon session was to condense the issues identified in the morning problems into action items that could be addressed through potential research. In the afternoon session, the hydrosystems group compressed the topics into the five action items listed below:

1. **Evaluation of Approved Erosion and Sediment Controls to Determine Best Management Practices**. This would include reviewing current literature, current BMPs and Pennsylvania methods to evaluate practices, monitoring BMPs in place, and evaluating field changes and responses to determine why they are done and their relative success. This project would be extended to two years after the completion of the I-99 corridor to complete the evaluation of the BMPs. It would require one faculty member and several graduate students over the life of the project. Instrumentation would be required and it would have to be determined whether the instrumentation would be done by the consulting firm Skelly and Loy Inc. or by Penn State. The estimated cost of this project is approximately $250,000/five years, which would include 25 percent of a faculty member's time and three graduate students.

2. **Hydrologic Modeling of Subsurface and Surface Quantity and Quality**. This would include determining areas that we want to model along the South Bald Eagle Creek watershed and collecting and analyzing all of the data generated to date; determining additional monitoring needs, calibrating the model, and comparing the results to design; and ultimately, developing a predictive water quantity and quality model that can reduce the amount of monitoring that is required by federal and state Agencies. PennDOT is being required to monitor quantity and quality of water at several locations upstream and downstream of the highway right-of-way where the embankment divides the watershed. There are several mechanistic-based watershed models that have been developed at Penn State's in the Civil and Environmental Engineering Department. The models can simulate river/stream flow, overland, and saturated/unsaturated subsurface flow through media modules and can be adapted to account for hydrodynamics, sediment transport, pollutant, fate, and transformation. It is proposed that the models be modified over a three-year time period and calibrated and used for prediction over the next two years. The intent of the model calibration would be to develop a good predictive tool that would allow PennDOT to significantly reduce the required 10 years of monitoring; it would also develop a tool that could be used for future sensitive environmental areas. Instrumentation would be required and it would have to be determined whether the instrumentation would be done by the consulting firm Skelly and Loy Inc. or by Penn State. The estimated cost of this project is approximately $125,000 per year, which would include two to three faculty and four graduate students.

3. **Hydrologic Monitoring**. This would include determining the existing monitoring system and the need and time line for additional monitoring, and assessing the impact to the hydrologic processes, including seep wetlands and subsurface pavement drainage. Extensive monitoring is currently being done by Skelly and Loy Inc. Additional monitoring would be needed to determine the effectiveness of the wetland mitigation. The instrumentation, which would include a faculty member and several graduate students, would have to be determined in a broader scope of work, but the estimated cost of the project would be approximately $300,000 /five years.

4. **Stream Restoration**. Part A would involve developing a case study on the Laurel-Oliver Run complex, including the review and design procedures of current restoration methodologies; developing regional curves, monitoring sediment and transport, and assessing the impact of the stream restoration practices at hydraulic structures such as culverts or bridges. Part B would include evaluating stream enhancements along the I-99 corridor. The estimated cost for part A, which would include one faculty and several graduate students, would be approximately $100,000 per year for five years. The cost for Part B would be dictated by the level of effort that PennDOT and Penn State personnel deem necessary.

5. **Evaluation of Wetland Design**. This would involve reviewing the objectives, methods, and designs for creating, enhancing, and preserving wetlands, and determining the criteria and methods for evaluation of wetland design and objectives. Some of the cost of monitoring wetlands has been included in the monitoring portion of the action items. However, because wetland mitigation is a problem for every state transportation department, it would be extremely beneficial to determine criteria and methods to evaluate the wetland design that state and regulatory agencies can accept, and use these criteria to evaluate the I-99 mitigation plans. At the present time, PennDOT does not have a one-for-one or one-for-three type of wetland mitigation policy; however, without an understanding of the effectiveness of man-made wetlands, each highway project becomes negotiable with an unknown cost. To accomplish this task, it is estimated that $125,000 per year would be needed to fund two faculty members and several graduate students.

MATERIALS AND CONSTRUCTION WORKSHOP

Session 3. Defining a Course of Action

Session 3 set forth the variables that should be considered in addressing the goals of the six broad areas of research and implementation. The scope of the work to be conducted on I-99 should be developed with these variables and principles. It was clear from the discussion that the focus should be on work that can potentially be accomplished on I-99. The variables and problem approaches were limited to those problem statements that will not interfere with the current bid schedule and offer only up-side potential.

Durability of Bridges and Structures

"There is a need to have bridge decks last 50 years"

Guiding performance objectives

- 50-year performance life
- 20-year maintenance free
- Need performance index

Bridge decks deteriorate because of the intrusion of salt and the eventual corrosion of reinforcing steel. There are three areas that should be addressed: (1) Chloride penetration, concentration, rate of diffusion, and time to threshold value at the reinforcing steel level; (2) Cracking frequency, opening size, distribution, depth, time of occurrence and causes; and (3) design parameters that encourage or discourage the deterioration of the deck. Below is a list of potential variables that should be considered in the I-99 study:

Approach:

(1) Chlorides
- surface barrier – silanes, siloxanes
- permeability reduction with silica fume, fly ash, or GGBFS
- change corrosion threshold
- alternative reinforcement, FRP, or Stainless steel
- elimination of chloride deicers
- different form of salt (spray, Mg or Ca cations or nitrate anions, or urea)

(2) Crack Mitigation
- synthetic fibers prevent microcracks (early cracks, and therefore later cracks)
- proportioning the concrete mix for low shrinkage (specific elements in the cement)
- steel fibers
- Type k cement
- cement fineness
- construction processes and curing

- thick cotton mats and the effect of poly backing
- combination of effects for best results
- water curing - for 10-14 days
- maximum concrete temperature
- pozzolans to lower heat of hydration
- ***Proposal to well document actions here after
- perform tests at the university and make correlations
- look at material, construction, curing, pumping, and design issues

(3) Design Issues
- skew angle
- vibrations
- + and – moment areas
- pour sequence
- composite and non-composite

Durability of Pavements

"There is a need to have pavements last 50 years before total reconstruction"

<u>Guiding performance objectives</u>

- 50-year performance life
- 20-year maintenance free
- Need performance index

Pavements deteriorate for a variety of reasons. Three general areas should be addressed in the I-99 corridor related to the prolonging the life of pavements: (1) the substructure on which pavements are built; (2) joint detailing and maintenance; and (3) construction practices that contribute to longer pavement life. The first of these was thought to be a problem on its own and addressed in topic 5. The other two pertain directly to the materials and construction of the driving surface. The variables for the last two are presented in the list below:

<u>Approach:</u>

1) Joints
   - dowel layout
   - seals or no seals
   - alternative sealing material
   - joint spacing
   - flexural strength of the concrete
   - aspect ratio of slabs
   - longitudinal joints or not
2) Construction Practices
   - curing practices
   - sawn joint depth and width

- CRCP
- RCCP
- documented construction practice
- includes weather, time, temp
- timing and texture direction
- surface grinding
- QC practices
- cement fineness

Contract Administration

"There is a need to improve contract administration"

Guiding performance objectives

- Reduction of time by 15 percent

The delivery of the product to the taxpayer is an important consideration in building any highway. Improving the contract administration to allow more innovative means of bidding, scheduling, and executing the construction contract has the potential to deliver the contract item(s) in a shorter period of time. The following items were identified as potential approaches to addressing the work:

Approach:

- A + B * (# of days) bidding
- prequalification for quality
- assessment of quality of contractor
- monitor schedules and compare
- incentives
- performance-based
- time-based
- ride quality
- 10-year warranty

Maintenance

"There is a need to increase the life of maintenance materials"

Guiding performance objectives

- 4-year maintenance cycles for marker and stripes and similar items
- More cost-effective solutions

The maintenance of line striping and pavement markers is a major expense for all the highway districts. A need exists to provide longer lasting solutions to these problems. The following items have been identified as potential approaches:

Approach

- test bed of potential striping and markers
- careful monitoring of performance for reflectivity and durability
- review of specs and recommendations

Subgrade / Subbase

"There is a need to evaluate and approve subbase materials and subgrade materials"

Guiding performance objectives

- Performance base and method of evaluation

The performance of base, subbase, and subgrade materials is critical to the long-term life of pavements. The continued marginal performance of these materials is an expensive problem to remediate. There is a need for a means to evaluate and predict the performance of materials placed beneath the pavements and around bridge structures. The following needs have been identified as potential implementation into the I-99 project:

Approach

- implement design recommendation of Drexel Work Order on geocomposites
- develop criteria for soil amendment
- implement monitoring of compaction w / modified proctor or other test
- provide and monitor tolerance on depth of asphalt bases
- vary and monitor effect of subbase materials
- use a separation fabric

Recycled Materials and Byproducts

"There is a need to optimize the use of recycled Pennsylvania materials"

Guiding performance objectives

- Determine optimum use and consume stockpiles in Pennsylvania

The integration of recycled, coproduct, and byproduct materials from throughout the Commonwealth is a priority for the department. The I-99 project provides an idea setting for implementing the recommendations from a PADOT sponsored research study. The parameters should be considered in the process of implementing the initiative within the I-99 project:

Approach

- Environmentally benign materials
- Embankments use and performance
- Sound walls use and performance
- CLSM
- Sink hole remediation
- Utility cuts and pipe backfill
- Ground water monitoring
- Fly ash, foundry sand and GGBFS for CLSM
- High volume fly ash
- Silica fume applications

Session 4. Ranking

Session 4 concluded the day's discussion by discussing the importance and applicability of the I-99 project and ranking ideas by their importance and potential for I-99. The discussion pointed out that each of the six areas is important to the Commonwealth. The benefits of the listed items are tangible and pertinent to the overall health of the highway infrastructure. The two questions asked of each member of the panel are listed below. The average results for each of the topics are shown below in Table 1.

1. MARK THE OVERALL POTENTIAL FOR THE INITIATIVES TO BE IMPLEMENTED ON THE I-99 HIGHWAY PROJECT (Scale 1-4 with 1 as greatest potential and 4 as least potential)

2. MARK THE OVERALL IMPORTANCE OF EACH OF THE POTENTIAL INITIATIVES, AS IT PERTAINS TO THE LONG-TERM BENEFIT TO THE COMMONWEALTH OF PENNSYLVANIA OR THE U.S. INFRASTRUCTURE (Scale 1-4 with 1 as greatest importance and 4 as least importance)

	1	2	3	4	5	6
Implementable on I-99	**1.2**	**1.4**	**2.5**	**2.2**	**1.5**	**2.2**
Importance to Improving Infrastructure	**1.2**	**1.3**	**2.6**	**2.1**	**1.5**	**2.9**

From these results, it can be clearly seen that improving the long-term durability of bridges and pavements is the top priority. Topic 1, Durability of Bridges and Structures, was selected by every participant as either first or second in importance and implementability in I-99. Topic 2, Durability of Pavements, was very close behind. Topic 4, Maintenance Issues and Topic 5, Subgrade/Subbase, were also recognized as very important topics that should not be overlooked. Topic 6, Recycled Materials, was seen as a topic that should be implemented in I-99, but not of top importance to improving the infrastructure even though it may contribute to the overall health of the Commonwealth. Topic 3, Contract Administration, was considered equally important and implementable in I-99. There was a strong recognition in the discussion that these are all important topics and their implementation into I-99 would greatly benefit the Commonwealth.

Budgetary considerations will play a role in implementing the topics in this discussion. When the I-99 program moves forward, the scope of work will have to be defined within financial constraints. However, the improved durability of bridges and pavements could more that return the additional cost of their construction and monitoring. The same can be said for each of the other topics, as each was considered in terms of developing a more cost-effective highway infrastructure.

Below are the variables that should be considered in determining the scope of work for I-99 in each of the 6 areas of research and implementation.

Durability of Bridges and Structures

1) Chlorides
- surface barrier – silanes, siloxanes
- permeability reduction with silica fume, fly ash or GGBFS
- change corrosion threshold
- alternative reinforcement, FRP or Stainless steel
- elimination of chloride deicers
- different form of salt (spray, Mg or Ca cations or nitrate anions, or urea)

(4) Crack Mitigation
- synthetic fibers prevent microcracks (early cracks, and therefore later cracks)
- proportioning the concrete mix for low shrinkage (specific elements in the cement)
- steel fibers
- Type k cement
- cement fineness
- construction processes and curing
- thick cotton mats and the effect of poly backing
- combination of effects for best results
- water curing for 10-14 days
- maximum concrete temperature
- pozzolans to lowers heat of hydration
- ***Proposal to well document acting here after
- perform tests at the university and make correlations
- look at material, construction, curing, pumping, and design issues

(5) Design Issues
- skew angle
- vibrations
- + and – moment areas
- pour sequence
- composite and non-composite

Durability of Pavements

3) Joints
   - dowel layout
   - seals or no seals
   - alternative sealing material
   - joint spacing
   - flexural strength of the concrete
   - aspect ratio of slabs
   - longitudinal joints or not
4) Construction Practices
   - curing practices
   - sawn joint depth and width
   - CRCP
   - RCCP
   - documented construction practice
   - includes weather, time, temp
   - tining and texture direction
   - surface grinding
   - QC practices
   - cement fineness

Contract Administration

1) A + B * (# of days) bidding
2) prequalification for quality
3) assessment of quality of contractor
4) monitor schedules and compare
5) incentives
6) performance-based evaluation
7) time-based
8) ride-quality
9) 10-year warranty

Maintenance

1) test bed of potential striping and markers
2) careful monitoring of performance for reflectivity and durability
3) review of specs and recommendations

Subgrade/Subbase

1) implement design recommendation of Drexel Work Order on geocomposites
2) develop criteria for soil amendment
3) implement monitoring of compaction w / modified proctor or other test
4) provide and monitor tolerance on depth of asphalt bases
5) vary and monitor effect of subbase materials

6) use a separation fabric

Recycled and Byproducts

1) Environmentally benign materials
2) Embankments use and performance
3) Sound walls use and performance
4) CLSM
5) Sink hole remediation
6) Utility cuts and pipe backfill
7) Ground water monitoring
8) Fly ash, foundry sand and GGBFS for CLSM
9) High volume fly ash
10) Silica fume applications

Summary and Recommendations

After listening to the problems and discussing the challenges related to materials and construction in the highway infrastructure, it has become clear that steps should be taken to extend the life of highways and pavements. The technical knowledge exists to construct an infrastructure that is both economical and long lasting. This includes integrating high performance concrete into bridges and pavement; improving the evaluation and treatment of the subgrade and subbase used to support pavements; integrating recycled or coproduct materials for a "green" highway; and investigating new techniques to administer contracts and decrease routine maintenance costs.

Extensive discussion in the past year with PennDOT, FHWA, TRB and ACI committees, and industry leaders, combined with data from other states, confirms that the small additional capital expense of high performance concrete (HPC) in new bridges and pavements can lead to substantial long-term cost savings. Interstate 99 is the ideal venue to implement those savings and technical improvements for the first time. It will require integrated leadership from within PennDOT, Penn State, and FHWA, and could make Pennsylvania the first state to fully demonstrate technical and fiscal feasibility of the project.

Several projects should grow from the year-long development of the I-99 initiative and the discussions with PennDOT, FHWA, and industry representatives. Four areas of research and implementation related to materials and construction could be reasonable addressed in the I-99 project: high performance concrete bridge decks, a materials performance database for pavements and structures, recycled materials integration into non-critical applications, and contract administration. Each of these is broadly outlined in the section below. A detailed scope of work should be determined with the district, PennDOT materials and test personnel, and Penn State investigators.

RECOMMENDED RESEARCH AND IMPLEMENTATION FOR I-99

1. Extending the Life of Concrete Bridges and Structures with High-Performance Concrete.

The durability of concrete bridge decks along the new section of I-99 is the single greatest concern. A panel of highway officials and industry experts ranked this of the highest importance and pertinence to Interstate 99 at a transportation forum at Penn State in July , 1998. Bridge decks currently last 25-30 years, whereas the beams and substructure last 50 or more years. Eliminating the need to replace bridge decks in the life of the structure would increase its value and change the way we address bridge design.

A proposed scope of work on the I-99 project is to

a. develop and use improved concrete mixture designs for bridge decks to reduce permeability, rate of hydration and chloride diffusion based on performance specifications,
b. reduce shrinkage cracking in bridge decks by reducing related early-age cracking, and
c. extend the life of bridge decks by using alternative reinforcement.

A proposed scope of work would include designing 10 deck sections to last a minimum of 50 years. This would include changing the mixture design, curing techniques, and reinforcing material in these decks. Ten HPC decks would be placed on representative sections of the project. The researchers would inspect and document each deck thoroughly throughout construction and monitor it after construction. The construction methods, formwork, and overhead would not be affected by this work. This project would change the proportions of concrete mixtures, curing methods and materials, and materials for reinforcement. These changes may increase or decrease the cost of some materials to the job, but would not typically change the handling or placement of the material. Estimated research costs would total $150,000/year for 5 years, with a long-term monitoring cost of $20,000 every 3 years. Approximately $100,000 of this cost is supplies, materials, sensors, and monitoring equipment. FHWA has committed to supplying the project with the high-performance concrete showcase mobile laboratory and to making the project a HPC showcase for national interest.

The variables and scope of work will be jointly agreed upon by PennDOT, Penn State, and FHWA. The variables to be included will be from the following list:

- Chlorides Diffusion Reduction
- surface barrier: silanes, siloxanes
- reducing permeability with silica fume, fly ash or GGBFS
- changing corrosion threshold
- using alternative reinforcement, FRP or stainless steel
- eliminating chloride deicers
- using synthetic fibers to prevent microcracks
- proportioning the concrete mix for low shrinkage
- steel fibers

- Type k cement
- cement fineness
- construction processes and curing
    - thick cotton mats and the effect of poly backing
    - using a combination of effects for best results
    - water curing for 10-14 days
    - maximum concrete temperature
    - pozzolans to lower heat of hydration
    - proposal to well document actions hereafter
    - perform tests at the university and make correlations
    - look at material, construction, curing, pumping, and design issues

2. **Database for Materials Performance**

The issues identified as most important in materials and construction were bridge durability and pavement durability. The pavement design issues are addressed in another work statement in this report, but the documentation and evaluation of performance of materials should be carefully addressed to clearly understand the variables contributing to performance evaluation. There is a need to document the construction process, the materials used, and the conditions under which they are placed and maintained. Tracking the performance of material used in Pennsylvania is not possible with the current pavement and bridge inventory system. The system needs a database of more specific construction and materials information and quantitative performance test data. Documenting the specifics of the materials used in concrete pavements and bridges, and for prestressed concrete girders, substructures and decks, is an important part of evaluating durability and life-time performance.

Periodic quantitative evaluation of the concrete provides a clear picture of the time-dependent properties (increasing strength and modulus, ingress of chlorides, shrinkage, decreasing permeability, conductivity and delamination). The videologging already done by PennDOT, tools developed in the SHRP program, and concrete tomography developed by the U.S. Army Corps of Engineers can greatly increase the quantification of the bridge and pavement performance. A database to monitor the long-term performance of I-99 will provide a blueprint for all districts to use for improving the life cycle of pavements and bridges in Pennsylvania. I-99 can be monitored in perpetuity to provide feedback for the Commonwealth and other states.

The proposed scope of work on the I-99 project is to (1) develop a materials and performance database for concrete in pavements and bridges along the highway; (2) conduct quantitative evaluation of concrete over time, including permeability, chloride intrusion, conductivity, modulus, compressive strength, scaling, delamination, and tomography; and (3) provide a means for PennDOT and highway engineers to remotely monitor and learn from the database. Estimated research costs are $120,000/year five years. Approximately $130,000 of this cost is for supplies, sensors, materials, and monitoring equipment. The U.S. Army Corps of Engineers is committed to partnering to provide tomography data on sections of pavements and bridges.

3. Using Recycled and Byproduct Materials

This area was identified as one of the top six areas of interest by PennDOT. The Commonwealth's highway infrastructure results in the creation of a great deal of waste materials (tires, asphalt, concrete, and steel). In addition, industry and the citizens of the Commonwealth create many byproduct and waste materials such as fly ash, foundry sand and blast furnace slag. Many of these byproducts are clean, uniform, high quality raw materials that can be used to construct and maintain the infrastructure. Incorporating these materials into embankments, soundwalls, pipe backfill and control low strength material for the I-99 project is an excellent opportunity to document and monitor the use of these materials. Glass, foundry sand, fly ash, tires and ground granulated blast furnace slag could all be used in various components of this project, would meet or exceed the performance standards set by current materials, meet and would be used in applications where they would be environmentally benign.

The proposed scope of work would assist in integrating recycled and byproduct materials into the I-99 project. Researchers would 1) monitor and evaluate the in-situ use of glass and tires in embankment and fill applications in non-roadway applications to provide protocol to all PADOT projects on the use of these materials; 2) monitor and analyze the results of using fly ash at 20-25 percent replacement level in concrete to reduce the cracking potential from heat and salt related issues while simultaneously improving the ASR resistance of concrete; 3) evaluate and validate the use of recycled and byproduct materials in flowable backfill; and 4) monitor and validate other components of the I-99 project that contain recycled materials (e.g. soundwalls and stabilized base material). The goal of this task would be to monitor the use of 20,000 tons of recycled materials. Estimated research costs would be $100,000/year over 5 years. Approximately $100,000 of this cost is for supplies, sensors, materials and monitoring equipment.

4. Contract Administration

The I-99 project provides an excellent opportunity to evaluate the use of alternative scheduling methods, assessment methods and performance standards. This topic was among the top six identified by PennDOT personnel and industry experts as having the potential to improve the highway infrastructure. Integrating a shadow schedule into the project could allow researchers to predict delays, progress, accelerations, and critical events more readily than classical CPM. Documenting the prequalification of bidders and comparing these qualifications to performance could change the manner in which bidders are selected in the future.

The proposed scope of work would combine several aspects of construction administration to evaluate the potential of alternative methods. The district would assist in writing the scope of the project to accommodate the bidding schedule. The work would likely document the qualifications of bidders and award winners. A parallel schedule would be created to track construction operations and compared to the required CPM. The work order would look at the potential for warranties, performance incentives and time incentives on I-99. Estimated research costs are $70,000/year over 5 years. Approximately $50,000 of this cost is for supplies, sensors, materials and monitoring equipment.

Other Projects

There were other topics brought up during the discussions. Because of the nature of I-99 and the short time period to implement the work, these projects may be more suitable for another area of the Commonwealth's system, or in "Corridor O," which is only now in the planning stages. These ideas include A+B contract bidding, high strength concrete girders for spans greater than 150 feet, durability testing of reflective materials, double-lift paving to optimize materials, and SHRP snow fence technology. There are many other problems and potential projects that could be addressed.

Structural Engineering Priorities for I-99

High Priority #1. Inability to accurately predict movement and stresses in curved and skewed structures during construction and service.

Introduction/Background

Increased implementation of curved and skewed bridges for new designs and replacement projects indicates that improvement is needed in design methodology, particularly behavior of systems during construction and effects of composite construction on force distributions. The Curved Steel Bridge Research Project (CSBRP) initiated by the FHWA examines curved steel bridge behavior and provides an extensive set of information on the behavior of curved girder bridges; however, limited information is available from field investigations of these structures. The I-99 Advanced Transportation Technology Test Bed presents a unique opportunity to instrument and study skewed and curved composite bridge systems during their construction and service life. This project will examine the behavior of a curved composite plate girder system and a selected number of skewed bridge systems through extensive field and analytical studies. The bridges will be instrumented during the construction phase and data will be generated over an extended period of time. Controlled field tests will be performed at various stages of the bridges' lives to examine behavior (flexural, shear, combined flexure, and shear deflections), and results from these studies will be compared to analytical and laboratory results. It is intended that this project will (1) provide comparative data to analytical models and experimental results from the CSBRP; (2) develop improved design guidelines specific to curved composite bridges in Pennsylvania; and (3) develop detailed and simplified analysis guidelines for curved composite bridges in Pennsylvania.

Approach

- Perform a literature review.
- Perform finite element analysis and design field instrumentation.
- Conduct data acquisition during construction phases.
- Document construction sequence and as-built structure.

- Interact with consultants/original designers to establish predicted behaviors.
- Perform controlled load testing.
- Validate current design methodology and construction sequence.

High Priority #2. Current seismic design standards create highly congested rebar conditions. Are the recently adopted seismic design provisions necessary for bridges in the Mid-Atlantic region?

Recently adopted seismic design provisions in the AASHTO Bridge Design Specifications have resulted in reinforcing configurations for new bridge piers that are in some cases not constructable due to the congestion of reinforcing bars. A question of proper concrete consolidation arises as well as the actual performance of this type of detail in a severe seismic event. In addition, a perceived whole scale seismic inadequacy of existing bridge support structures in the Mid-Atlantic region, particularly single and multi-column pier bents, has developed. Current small scale studies are underway to investigate the actual capacities and seismic survivability of existing designs; however, a larger scale study is warranted to evaluate the effects of an eastern seismic event on bridge pier details of this type. Alternate reinforcing details are required for mid-to-low risk regions to facilitate constructibility and to reduce the impact on construction delays due to this congestion.

<u>Approach</u>

- Perform a literature review.
- Assess seismic hazard to highway bridges in the Mid-Atlantic Region.
- Identify design/construction problems associated with mitigation of seismic issues
- Investigate the option of revising the seismic design provisions for the Mid-Atlantic region and Pennsylvania from what has been accepted practice in California, as the seismic risk may be considerably different.
- Supplement current contract designs, review current design provisions, and recommend revisions
- Develop and evaluate alternate reinforcing materials
- Evaluate the use of different types of concrete (smaller aggregates, etc. to get around rebar) if seismic criteria cannot be changed
- Develop cost effective and constructable seismic design provisions for highway structures in Pennsylvania
- Cost-benefit analysis of seismic resistant strategies

High Priority #3. There is no established method for predicting movement and stresses in integral abutments.

<u>Introduction/Background</u>

There is currently no reasonable methodology to predict movement and long-duration stresses in integral abutment bridges. This project will examine the behavior of integral abutment bridges through field and analytical studies. Selected abutments, piles, and major components of jointless bridges will be instrumented to monitor field behavior during construction and extended periods of time. Some problems such as preventing degradation of the approach slabs and efficiently orienting piles beneath the abutment sill still exist when integral abutment designs are used. The I-99 project offers a unique opportunity to examine these deficiencies and the behavior of integral abutment systems as a whole both during and after construction. Sensors measuring strains, relative motions, and temperature changes will be placed in areas that are typically inaccessible when completed structures are studied. For instance, behavior of the approach slabs and compression seals under daily and long-term temperature variations will be studied along with soil pressure influences on the backwalls and wingwalls and behavior of piling beneath the abutments. Experimental data will be compared to predictions from common computational design tools. A series of analytical studies will be initiated to determine a best approach for predicting forces developed within various parts of the abutment system.

Approach

- Perform a literature review.
- Perform finite element analysis and design field instrumentation.
- Conduct data acquisition during construction phases.
- Document construction sequence and as-built structure.
- Interact with consultants/original designers to establish predicted behaviors.
- Perform controlled load testing, both short and long term.
- Validate current design methodology and construction sequence.

High Priority #4. Inability to consistently prevent *deck cracking*.

Each year transportation agencies across the US invest tens of millions of dollars in concrete bridge deck repair, replacement, and rehabilitation. These projects not only consume resources, but cause significant delays for the motoring public on highways and roads. Numerous variables influence the quality and long-term performance of concrete bridge decks, including mix design; placement practices and sequences; curing procedures; reinforcing spacing, position, and type; girder stiffness, length, and spacing; traffic frequency, impact, and loading; maintenance; and deicing salts. The important variables influencing bridge deck performance must be controlled and studied in order to determine the factors that result in the most durable bridge deck. The I-99 test bed offers a unique opportunity to conduct such a study of 100+ bridge decks and to create a database of the long-term and short-term effects of these variables.

Approach

- Perform literature review.

- Create a 'best practices' document for casting, curing, and mix designs based on available literature.
- Influence outcomes using competing procedures and compare the effects of different variables (controlled), and/or maintain consistent procedures and analyze the results (uncontrolled).
- Develop a list of variables and document those on a sample group of bridges (precast, composite, or other similar groupings).
- Develop a database.
- Document and control as many variables as possible in the control group.
- Use a multi-span bridge and control different variables when pouring the different spans

High Priority #5. There is a need to reassess design criteria for plain elastomeric bearings, in terms of performance, construction, and capacity. The use of elastomeric bridge bearings continues to present numerous difficulties, particularly as it relates to prediction of performance, delays in construction due to delivery, initial high cost. A better defined design relationship between shear, compression, and rotation is needed to facilitate efficient design as well as environmental performance.

Approach

- Perform a literature review.
- Develop a testing program for shear, compression, and rotation to failure.
- Evaluate low- and high- temperature performance (environmental evaluation).
- Document performance of bearings that are already in place.
- Recommend specification modifications.

The following problems were considered important as research initiatives and may be considered should funding be available:

Priority #6. Inaccurate design ***methodology for culverts under high fill.***

Priority #7. Lack of accurate ***strength prediction for curved steel girders*** within composite systems.

Priority #8. The need to understand the requirements of ***embedded sensors*** in relation to power sources and communication.

RIGID PAVEMENT PERFORMANCE WORKSHOP

Sessions III and IV: Generation and rating of approaches and action items.
Problem approaches were discussed and generated for each of the six groups of issues detailed above. These selected approaches were considered as possible research action items. The group limited the listed approaches to those with potential for at least some action on I-99.

The research approaches were rated on a scale of 1 (most potential) to 4 (least potential) for importance and potential impact. The ratings are summarized in the table below. The ratings were performed for individual action items; however average ratings for each group are also shown. Both the number of top priority rankings and the average rating for each action item are shown.

Rating of Approaches and Action Items for Rigid Pavement Performance		
	No. 1 Rankings	Average Rating
Group: Monitoring		1.778
Seasonal Monitoring of Subgrade	9	1.643
Permanent Monumentation of Test Section	8	1.769
Instrumentation Plan	7	1.923
Group: Pavement Design		1.931
Evaluation of Performance of Joint Design Parameters	10	1.286
Evaluation of Noise & Skid Resistance of Various Texture	6	1.786
Widened Lanes	3	2.071
Utilization of Cost/Optimization Tools (Performance Models)	4	2.154
Diamond Grinding	3	2.357
Group: Construction Issues		2.131
Evaluation of Construction Parameters & Effects on Pavement Performance /Variability of Material Characteristics & Effects on Pavement Performance	8	1.786
Documention of Construction Practices, Materials & Inspections	6	1.929
Development of Performance Criteria & Compare Against the Product	4	2.143
Innovative Bidding and/or Contract Procedures	2	2.214
Utilization of Mobile Concrete Lab	3	2.357
Review of Bonus/Penalty Criteria	2	2.357
Group: Truck – Pavement System Interaction		2.214
Instrumentation to Analyze Wheel Load to Determine Maintenance Time	7	2.214
Group: Subbase		2.232
FWD to Examine Uniformity of Subgrade	8	1.571
Varying Depth and Gradation	7	2.071
Daylighting Subbase	3	2.500
Design For Frost	1	2.786
Group: Concrete Mix Design		2.268
Durability of Different Mix Design	7	1.786
Contractor's Mix Design for a Specified Lab Flexural Strength	4	2.071
Accelerated Concrete	4	2.357
Manufactured Sand under Shoulders	1	2.857

I-99 Research Work Plan

Based on the ratings shown above and even more strongly on the group discussion, it is clear that appropriate, coordinated, and extensive monitoring of any research undertaken is a top priority. The monitoring must be consistent between pavement research items and other research areas. Potential monitoring activities were discussed, but the details will depend on the selected experiments and analysis requirements. Extended performance monitoring will be essential to the success of any pavement-related experiment on I-99.

The most highly rated specific research approaches for rigid pavement performance are:

- *Evaluation of performance of joint design parameters*
- *Use of widened lanes*

  Potential joint design experiments were outlined in the conference white paper. These experiments should complement and be coordinated with the planned I-80 research, as well as other current research. Potential joint research includes dowel layout and type, dowel coatings, reservoir size and shape, sealant material, and joint spacing.
- *Testing (Falling Weight Deflectometer) to examine uniformity of subgrade*
- *Seasonal monitoring of subgrade*

  Subgrade variability, characterization, and improvement needs have a significant impact on pavement design and construction. Research in this area should be coordinated with the geotechnical area.
- *Evaluation of noise and skid resistance of various concrete surface textures*
- *Durability of different PCC mix designs*
- *Evaluation of construction parameters and materials variability effects on pavement performance*
- *Documentation of construction practices*
- *Variation of depth and gradation of subbases*

  Some construction problems and suspected performance problems have been experienced with open-graded bases. Other drainable bases have been used with cement or asphalt stabilization. Of particular concern in the conference discussions were the gradation specifications for bases. Test sections with base course variations could be implemented on the I-99 pavement.

TRAFFIC AND ITS WORKSHOP

Breakout Session III

The third session consisted of identifying infrastructure needs associated with each of the six general problem categories. In addition, the group identified several "global" needs and requirements that would benefit several, if not all, of the problem areas. These global needs are listed below, along with the specific needs identified under each of the six general problem areas.

Global Needs
- Backbone communications network (communications fiber)
- Traffic data "warehouse" (GIS mapping capability, Internet access)
- System integration

Maintenance / Facility Management
- Routing and Scheduling Algorithms for Salting / Gritting and Snow Removal Vehicles
- Automated Guidance for Maintenance Vehicles
- Monitoring of Tire Loads on Pavement (weigh-in-motion for maintenance)

  Needs
  - Weather and roadway condition monitoring (roadway temperature, amount of salt)
  - In-vehicle GPS locators
  - Magnetic pavement markings
  - Weigh-In-Motion for tire loads

Incident Management and Emergency Response
- Emergency Response to Hazardous Material Spills
- Incident Prediction, Detection, and Classification
- Incident Response

  Needs
  - Central location for receipt and processing of incident information
  - Video surveillance cameras
  - Weather and roadway condition monitoring / sensors

Traveler Information
- Driver Advisories During Adverse Weather Conditions
- Optimization of Highway Signing Design
- "Smart" Highway Illumination
- Driver Information during Special Events
- Driver Information for Food and Lodging Services

  Needs

- Variable message signs (special event, food and lodging info, routing, speed limits, etc.)
- Weather and roadway condition monitoring
- Cellular service
- Highway advisory radio
- Blockhouse facility and gantries for highway illumination and signing (feedback and control capabilities)

Commercial Vehicle Operations

- "Black Box" use in all vehicles
- Pre-clearance Commercial Vehicle Operations Monitoring
- On-board Vehicle Rollover Technology
- Automated Enforcement Screening Technologies
- Commercial Vehicle Driver Information

Needs

- Weather and roadway condition monitoring capabilities
- Roadway beacons / transmitters ("smart strips") to transmit highway design and traffic information
- State-of-the-art roadway inspection site(s)
- Weigh-in-motion capabilities (for tire, axle, and gross vehicle weights)

Public Transportation

- Ride Matching and Fleet Management Software
- Regional Bus Service and Information System

Needs

- Internet access kiosks
- Transfer / park-and-ride stations near I-99 corridor
- In-vehicle communication / GPS for bus dispatching and monitoring

Traffic Management

- Special Events
- Signal Systems Coordination
- Automated Screening Technologies for Safety and Enforcement (traffic violations)
- Recurring Congestion

Needs

- Vehicle detection (to obtain flow, speed, occupancy, vehicle classification)
- Real-time traffic signal control capabilities (throughout the corridor)
- Variable message signs (on I-99) for parking management during special events
- Real-time parking lot occupancy information

- Traffic monitoring on approach streets
- Ramp metering
- Capability for directional lane changing

Breakout Session IV

The final session consisted of prioritizing each of the specific infrastructure needs according to a "high," "medium," or "low" ranking. The global needs were treated separately, and were considered "high" because they address a broad range of problem areas. The final rankings are shown below.

<u>High Global Needs</u>

- Transportation Management Center (TMC)
- Backbone communications network (communications fiber)
- Corridor-wide data "warehouse" (serves operations and research functions; may be located at TMC)
- Institutional coordination
- System integration

<u>High Needs</u>

- Weather and roadway condition monitoring (roadway temperature, amount of salt)
- Variable message signs (special event, food and lodging informatioin, routing, speed limits, etc.)
- Highway advisory radio
- Magnetic pavement markings ("Smart Strips"), roadway beacons and/or transmitters to transmit highway design and traffic information
- Vehicle detection (to obtain flow, speed, occupancy, vehicle classification on I-99 corridor and adjacent system)
- Video surveillance cameras
- Real-time traffic signal control capabilities (throughout the corridor)
- Weigh-in-motion capabilities (for tire, axle, and gross vehicle weights)
- "Smart" highway illumination (feedback and control capabilities)

<u>Medium Needs</u>

- In-vehicle communication and GPS, for dispatching and monitoring emergency, maintenance, and transit vehicles
- Transfer / park-and-ride stations near I-99 corridor
- State-of-the-art commercial vehicle inspection site(s)
- Capability for directional lane changing
- Test facility and gantries for highway signing

<u>Low Needs</u>

- Cellular service

- Internet access kiosks
- Ramp metering
- Real-time parking lot occupancy information

<u>In attendance:</u>

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Hugh Mose	Centre Area Transportation Authority
Martin Pietrucha	The Pennsylvania State University
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Traffic and ITS: High-Priority Problems and Recommended Infrastructure Needs

Participants in the Traffic and ITS technical area identified a total of 22 problem/opportunity areas, which were subsequently categorized as either a "high," "medium" or "low priority" need. This section describes each of the 11 problem/opportunity areas associated with "high-priority" needs, categorized by the general areas identified under the national ITS architecture. High-priority global infrastructure needs that would benefit most, if not all of these problem categories are outlined at the end of the document.

High Priority Problem /Opportunity Areas

<u>Maintenance / Facility Management</u>

- ***Routing and Scheduling Algorithms for Salting/Gritting and Snow Removal Vehicles (Approximate Penn State Cost: $50,000/yr for two years)***
  Advanced sensor technologies and other surveillance devices permit estimates (or forecasts) of current (or future) snow levels and the presence of ice on short stretches of roadway to be made. This information is automatically relayed to a central computer that determines how to optimally route and schedule snowplows and salting/gritting vehicles.

  High-Priority Infrastructure Needs:
  - Weather and roadway condition monitoring

- ***Automated Guidance for Maintenance Vehicles (Approximate Penn State Cost: $70,000/yr for two years)***
  I-99 provides the opportunity for research, development, and full-scale implementation of automated guidance systems for maintenance vehicles. The precision roadway maintenance facility could be used to explore the use of vehicle guidance systems for maintenance functions. The facility provides a test-bed for research and development of vehicle guidance systems, and provides grounds for full-scale implementation of these technologies.

  High-Priority Infrastructure Needs:
  - Magnetic pavement markings ("Smart Strips"), roadway beacons and/or transmitters to transmit highway design and traffic information

- ***Monitoring of Tire Loads on Pavement (Approximate Penn State Cost: $50,000/yr for four years)***
  This system permits tire pressure on the inside and outside tires of heavy vehicles to be monitored. The data can be used to estimate pavement life for maintenance purposes, and/or enforce vehicle load limits.

High-Priority Infrastructure Needs:

- Weigh-in-motion capabilities (for tire, axle, and gross vehicle weights)

Incident Management and Emergency Response

- ***Incident Prediction, Detection, Classification and Response (Approximate Penn State Cost: $120,000/yr for three years)***
  A "smart" mayday system could be installed along the I-99 corridor. The system would have direct contact with PennDOT maintenance facilities, local police, fire, EMS, and medical facilities, resulting in decreased response times and allowing the appropriate response agencies to be notified of the nature of the incident. GPS and communications technology (such as cellular technology) could be utilized.

  High-Priority Infrastructure Needs:
  - Weather and roadway condition monitoring
  - Video surveillance cameras

- ***Emergency Response to Hazardous Material Spills (Approximate Penn State Cost: $50,000/yr for two years)***
  Mobile communication technologies provide emergency response units with real-time information concerning roadway incidents involving vehicles carrying hazardous substances and other highway accidents. This results in decreased response times and increased efficiency during spill containment and incident management phases.

  High-Priority Infrastructure Needs:
  - Weather and roadway condition monitoring
  - Video surveillance cameras

Traveler Information

- ***"Smart" Highway Illumination (Approximate Penn State Cost: $250,000/yr for three years)***
  I-99 provides the opportunity for research, development, and full-scale implementation of roadway and interchange illumination technologies. A roadway illumination facility could be developed to test different types of roadway and interchange illumination. The facility could be composed of tracked gantries that could be used to vary lateral and longitudinal placement, and height of luminaires. It could also be used to test different types of lighting systems (i.e., various types of bulbs, fiber optic, etc.). The systems could also be used to test various types of "smart" lighting that varied with ambient lighting and weather conditions.

  High-Priority Infrastructure Needs:
  - "Smart" highway illumination (with feedback and control capabilities)

- ***Traveler Information Center (Approximate Penn State Cost: $225,000/yr for two years)***
  Traveler information, when provided by a variety of sources, contains unreliable, conflicting and contradictory messages that undermine and may defeat the purpose of information provision. A real-time information clearinghouse (Traveler Information Center [TIC]) for the I-99 corridor would allow the collection of complementary and overlapping information, verification of the validity of information, and the broadcasting of messages to all travelers using different media of communication (e.g. the Internet, radio, variable message signs, 800 numbers, daily fax for a fee, etc.).

Commercial Vehicle Operations

- ***On-Board Vehicle Rollover Technology (Approximate Penn State Cost: $50,000 for two years)***
  This system would enable drivers of heavy vehicles to receive information (precautions, warnings and alarms) from the highway infrastructure regarding curve geometry in order to avoid vehicle rollovers.

  High-Priority Infrastructure Needs:
  - Magnetic pavement markings ("Smart Strips"), roadway beacons and/or transmitters to transmit highway design and traffic information

- ***Use of Vehicle Data Recording Devices (Black Box) for Safety Management (Approximate Penn State Cost: $40,000/yr for two years.***

  Vehicle manufacturers are increasingly installing and upgrading the capabilities of data recording devices (black boxes) in passenger vehicles. The creation of an I-99 smart corridor would permit deployment of an ITS accident causation information capability. The capture of black box data would enable analysis of the data's accessibility and reliability and the efficacy of using such data to address numerous safety concerns (e.g., maintenance, highway design, vehicle design, driver error).

Traffic Management

- ***Traffic Management and Parking during Special Events (Approximate Penn State Cost: $70,000 for three years)***
  Drivers, especially those unfamiliar with the area, need to be properly guided to the designated parking lots, avoiding areas of increased congestion, during special events at Beaver Stadium and the Bryce Jordan Center. Real-time information regarding the availability of parking and current traffic conditions will reduce the delays and travel times experienced by drivers. Advanced technologies can be used to collect and disseminate such information along the I-99 corridor, as drivers approach the State College area.

High-Priority Infrastructure Needs:

- Variable message signs (special events routing)
- Vehicle detection (to obtain flow, speed, occupancy, vehicle classification on I-99 corridor and adjacent system)
- Real-time traffic signal control capabilities (throughout the I-99 corridor)

- ***Real-time Integrated Traffic Signal Control System Throughout the I-99 Corridor (Approximate Penn State Cost: $70,000 per year for three years)***
  Currently, several different agencies operate and maintain the various traffic signal systems in the State College area. The presence of the new I-99 facility creates a unique opportunity to address traffic signal control problems within the overall traffic management scheme for the region, including all interchange traffic signals. A state-of-the-art Traffic Management Center (TMC) would serve to integrate and coordinate the operation and maintenance of the various signal systems at a single location.

High-Priority Global Needs

- **Transportation Management Center (TMC)**
  The presence of the new I-99 facility creates a unique opportunity to address traffic signal control problems within the overall traffic management scheme for the region, including all interchange traffic signals. A state-of-the-art Traffic Management Center (TMC) would serve to integrate and coordinate the operation and maintenance of the various signal systems at a single location. Using state-of-the-art computer and communications technologies, the TMC would be enhanced through access to real-time traffic data, on-line control of individual signal displays, and incident detection and response capabilities, resulting in a reduction in overall operation and maintenance costs, delays and stops for motorists, and mobile emission levels. In addition, a real-time information clearinghouse (Traveler Information Center [TIC]) for the I-99 corridor could be created at the TMC, to collect complementary and overlapping information, verify the validity of that information, and broadcast messages to all travelers using different communication media.

- **Backbone Communications Network**
  A communications network is necessary to link the various technologies to one another and to the TMC.

- **Corridor-wide Data "Warehouse"**
  The data warehouse is envisioned as a single location where data is received, processed, analyzed, and disseminated to the public, traffic analysts, researchers, etc. The warehouse would serve both operations and research functions. It may be located at the TMC.

- **Institutional Coordination**
  This is crucial to ensure seamless administrative and operational connections between the many parties involved, including PennDOT, the Pennsylvania State University, emergency and police services, etc.

- **System Integration**
  This is necessary to ensure that the various sub-systems and technologies work together efficiently as part of the larger I-99 corridor.