Research Plan for Concrete and Concrete Pavements

(12-10-'00)

Introduction

There has been a continuous effort put forth towards the improvement of the use of portland cement in concrete construction since it was patented by the Englishman, Joseph Aspdin, in 1824. Over a century later, the birth of the interstate highway system in the United States intensified the need to learn more about portland cement concrete and concrete pavements. Today, the focus has switched from constructing to maintaining and rehabilitating the interstate with over $20 billion[1] being invested in highway pavements each year. It is essential that the knowledge in the areas of concrete and concrete pavements continues to evolve to insure this money is being invested wisely and future needs will be met. For this reason, it is important to continually evaluate, refine and, when necessary, redefine goals for the future and the knowledge that must be gained to obtain these goals.

This document is a compilation of the ideas and opinions of the Committee for Research on Improved Concrete Pavements, the Innovative Pavement Research Foundation (IPRF) and the Federal Highway Administration (FHWA) as well as other long-standing experts in the pavement community. The purpose of this document is to provide the initial ground work for the development of a research plan that, when carried out, will provide the tools necessary to make wise investment decisions with respect to the analysis, design, construction, maintenance and rehabilitation of concrete pavements. The objectives are to: 1) establish the goals for future concrete pavements; 2) identify the research needs required to fulfill these goals based on the current state-of-the-art; and 3) develop a research plan detailing how these needs can be met.

Goals

The first objective is to establish intermediate goals that will serve as stepping-stones to the ultimate goal of providing high-quality, cost-effective concrete pavements for future generations. A list of goals that would provide the greatest contribution to the improvement of concrete pavements was generated based on the opinions and ideas expressed by the committee and are provided below. A detailed description of each of the six goals is provided in appendix A.

Goals for Future Concrete Pavements

1. Achieve Desired Design Expectations Economically
2. Extend Pavement Life while Reducing Maintenance Requirements for High-Volume Roadways
3. Reduce the Time Required for Construction, Rehabilitation and Reconstruction
4. Improve the Performance of Recycled Materials used for Constructing Concrete Pavements
5. Improve and Quantify the Quality Control/Assurance Processes for Concrete Pavement Construction and Rehabilitation
6. Implement Tools and Methodologies Necessary for Making More Cost-Effective Decisions

Research Needs

Next, research needs that must be addressed to accomplish these goals were identified. A literature review was performed to summarize research in progress and research recently completed. This resulted in the elimination of some previously identified research needs that were already being addressed, and the addition of other research needs that had not been considered. Some of the goals and research needs established here closely follow those identified in the blueprint and action plan for *Creating a New Generation of Pavements*[4] published by the IPRF in 1998 and in *Building for the Future: A Technology Program for Portland Cement Concrete Pavements*[3] published by FHWA in March 1999. An outline of the list of research needs that must be fulfilled to achieve each goal is provided in appendix A, along with more detailed descriptions of the goals. It must be emphasized that this is by no means an exhaustive list of research needs in the area of concrete pavements. This list is restricted to the research needs required to obtain the outlined goals. Issues, such as traffic forecasting, that do not pertain solely to concrete or concrete pavements are also not included in this research plan.

Research Plan

It is unrealistic to believe the research needs for obtaining these goals will be met by any one allocation of research monies. These goals can only be achieved through the collective effort of all of the organizations providing funding for concrete pavement research. Therefore, the final step is to develop a research plan that can be used for coordinating the collective efforts of the funding agencies to insure the research needs are fulfilled and the goals are obtained in a systematic fashion. This process consists of first developing a table to organize and prioritize the research needs and then using the table to produce a flow chart laying out the order in which the research should be completed.

All the research needs from the outline were categorized by subject and placed in the first column in table 1 of appendix B. The goal or goals the research need would help to obtain is listed directly after the research need. Recently completed, on-going or pending research projects that relate to a research need identified were added to column four. Research projects that should be completed before the research need is addressed are listed in column three. The research needs were then assigned a priority level ranging from 1 to 3 (with 1 being the highest level of priority and 3 being the lowest level) based on the urgency in which the need should be met and the dependence of each need on the completion of other needs. This information is placed in column two of table 1. The year that the research need should be funded in accordance with the established research plan is also provided in column 2 of table 1.

To stress these similarities between this research plan and the research plans of FHWA and IPRF, the research needs identified by IPRF or FHWA, along with research needs that are similar to those identified by IPRF or FHWA, are color coded in table 1. Research needs that are being addressed by FHWA and IPRF funded projects are also indicated along with research projects being addressed by agencies other than FHWA and IPRF. Most of the research of national focus funded by other agencies is funded by

NCHRP. The review of research-in-progress showed many state departments of transportation, as well as Canada, are also making significant contributions in the areas of concrete and concrete pavement research. These projects should be used as the foundation from which a national perspective in these research areas can be established. The significance of these contributions are sometimes masked because they frequently are small scale and of local focus. Some effort will be required to understand how these projects contribute to national goals before work can be initiated on any given research project.

The information provided in table 2, provided in appendix C, was extracted from table 1 and then reorganized to provide an easier format for evaluating the level of priority assigned to each research need. Table 2 also provides as an intermediate step in showing how the research plan presented in appendix D was developed based on the information provided in table1. Table 2 contains all of the research needs identified in table 1 but the research needs are categorized according to the level of priority each need has been assigned. Column one in table 2 contains the description of the research needs and each description is preceded by a number that can be used to cross-reference the research needs in table 2 with those in table1.

The final step was to develop a flow chart providing a systematic order in which the research needs should be addressed. A three-tier flow chart was developed with each tier representing a different level of priority. The research needs from table 1 were separated into three groups based on the level of priority they were assigned. Level 1 research needs were addressed first by ranking them based on the following criteria:

1. The importance of the goal the research need helps to obtain
2. The importance of that research need in obtaining the associated goal
3. The dependence of a need on the completion of another need
4. The urgency of the need

The year the research need will be funded was determined based on its ranking and the dependence of the research need on the completion of other research needs or on-going projects. The flow chart was developed assuming at least ten projects would be funded each year. The number of projects that actually get funded each year might be higher or lower than ten depending on the level of participation from other funding agencies beyond that of FHWA and IPRF.

Priority level 2 research needs were ranked after the year for funding was determined for all level 1 research needs. The year for funding each level 2 research need was then determined based on the same criteria used for level 1 research needs. Finally, level 3 research needs were ranked and placed under an appropriate year to be funded. The research needs with the highest level of priority should be funded first for any given year.

Each research need is identified in the flow chart according to the labeling system established in table 1. Table 1 should be used to cross-reference the label of the research need with its appropriate description. The goal associated with the research need is also provided in the flow chart. The research needs provided in the flow chart are placed either in a circle or an octagon. The octagons and circles are color coded according to the goal, or goals, which that research need will help to obtain. The circle represents research needs that are not dependent on the completion of other research needs or research projects that have already been funded or are pending. The research needs in the octagons should not be funded until the research project (or projects) referenced below the research need has been completed and it is determined additional research still needs to be performed and the tools necessary to perform the research are available. The dashed octagons represent research needs that might be met by currently on-going or pending research projects and the results of these projects should be evaluated after they are completed to determine if the research need should still be funded. The solid line octagons represent research needs that cannot be met until other research needs have been completed so that the tools necessary to fulfill the research need are available. Solid lines are used to connect research needs when the completion of one need is dependent on the successful completion of another need (or needs). Dashed lines connect research needs when the funding for a research need may not be necessary depending on the outcome of another research need (or needs).

The three tiers are interdependent since the completion of research needs in one tier may be dependent on a research need in another tier. Arrows have been included in the flow chart to help depict these relationships. The funding of research needs in the lower priority level tiers for any given year is also dependent on the number of research needs already programmed for funding from a tier with a higher level of priority.

An evaluation of the research plan should be performed each year to insure the goals and the research needs to obtain these goals have remained valid. The progress made towards obtaining the goals must also be evaluated by identify the research needs that have been fulfilled by the research completed during that year and determining if any additional research must be fulfilled for the goals to be obtained. Revisions should be made to the research plan each year by updating the flow chart based on 1.) the number of projects funded the previous year; 2.) the status of research in-progress and 3.) the results of research projects completed during the previous year. The updated flow chart must reflect the progress made and the research areas still needing funding as determined during the yearly evaluation.

Concluding Remarks

The research plan that has been presented is only the first step of an iterative process. A comprehensive research plan of such magnitude will require the input and ideas of many experts in the areas of concrete and concrete pavements. Although the advice from several experts has been obtained, the input from many others must still be solicited to help define the future goals, the research needs for obtaining these goals and the order in which these needs should be prioritized. There must also be agreement on the process being used to formulate the research plan. Through the iterative process of gaining feedback from the experts and implementing the input into the research plan, a successful research plan can be developed.

The success of this work plan is dependent on the acceptance and commitment to the work plan by the pavement community. The work plan must earn the acceptance and commitment of the pavement community by establishing goals and methods for obtaining these goals that are widely accepted. This requires a research plan that is constructed by consensus. It is for the better of the future of concrete pavements that a unified effort be put forth towards the improvement of concrete and concrete pavements. The accomplishments that can be achieved by combing our energy and resources will far out-weight that which can be accomplished by individual efforts.

References

1. “Pocket Guide for Transportation Statistics,” Publication No. BTS 98-S-02, Federal Highway Administration, Washington, DC, Dec. 1998.

2. “Building for the Future: A Technology Program for Portland Cement Concrete Pavements,” Federal Highway Administration, Washington, DC, March 1999.

3. “Creating A New Generation of Pavements: A Blueprint for Portland Cement Concrete Pavements,” American Concrete Paving Association, Skokie, IL, 1997.

4. “Creating A New Generation of Pavements: An Action Plan to Execute the Blueprint for Portland Cement Concrete Pavement Research,” Innovative Pavement Research Foundation, Skokie, IL, August 1998.

5. “Get In, Get Out, Stay Out,” Transportation Research Board, National Academy Press 2000, Washington, DC, 2000.

6. “Developing Long-Lasting, Lower-Maintenance Highway Pavement Research Needs,” Transportation Research Board, National Academy Press, Washington, DC, 1997.

APPENDIX A

Outline of Research Needs

Outline of Research Needs

1. **Achieve Desired Design Expectations Economically**
   The goal when designing a concrete pavement is to achieve an established design life in the most economical means possible. Accurate pavement response and performance prediction models must be used to accurately predict the life of the pavement so that the pavement does not fail prematurely or extend significantly beyond the design life. Although a premature failure would be less desirable, there are also negative aspects associated with constructing pavements that extend significantly beyond their design life, such as, allocating more money than necessary towards one project when this money could be better spent on other projects. The pavement design must also be performed with consideration to the materials that will be used to construct the pavement. The construction materials used must be the most economical materials available while still having sufficient strength and durability to achieve the design life of the pavement. The following research needs must be addressed so that an economical pavement can be designed knowing that the design life will be achieved.

   - **Concrete**

     A. Chemical admixtures

     1. Characterize interactions between admixtures and between admixtures and cementitious materials.

     B. Aggregate

     1. Develop a procedure for identifying the most cost-effective aggregate source for a construction project based on the cost of the material, which includes consideration of haul distances, the quality of the material, needed mix design adjustments, and projected long-term PCC performance.

     2. Identify procedures that can be taken to protect existing aggregate sources from urban development and to access sources that are currently difficult to retrieve because of environmental concerns and/or the presence of existing urban development.

     3. Develop new techniques for obtaining good performance from lower quality aggregates that may be available locally for use in PCC.

     4. Develop a procedure that uses test methods that characterize the quality and durability of an aggregate to identify pavement and mix design components needed to optimize the performance of the pavement.

     5. Develop tests that can identify durable aggregates before the quarry wall is mined.

     6. Develop a test procedure or revise currently available procedures capable of rapidly determining the alkali-silica reaction (ASR) potential of *concrete mixtures*.

     C. Cement

     1. Identify the effects of the chemical composition and fineness of cements on the mixture and improve classification of cements.

2. Develop a method for determining the permissible alkali content based on the type of aggregate and the mixture that will be used.

D. *Water-to-cementitious ratio (w/c)*

1. Develop a systematic approach to determine the optimum w/c and permeability for each project based on the relationship between cost, constructability and durability.
2. Provide guidelines for determining the w/c required to improve the performance of an aggregate source based on the durability of the aggregate.
3. Define the lower envelope of w/c's that can be used without excessive micro-cracking or self-desiccation occurring when considering the climatic conditions during paving and the curing techniques utilized.
4. Develop a quick, reliable test procedure to determine the water-cement ratio immediately before concrete placement.

E. *Concrete Mixture*

1. Determine the cause of the durability-related premature deterioration problems currently being encountered.
2. Develop modified or improved methods of rapid and reliable testing and assessing the damage of freeze-thaw test specimens, building upon findings from a previous SHRP (C203) study.
3. Develop a mechanistic approach for designing concrete mixtures. Desired fresh concrete properties and hardened concrete properties will be the design objectives, which would be selected based on the pavement design, the construction techniques to be utilized and both the construction and long-term environmental conditions. The output should include types and quantities of materials, the order in which the materials should be combined and required mix times.
4. Define adjustments required to take a mixture design from the lab to the field. This would include quantifying the effects of mix times for various types of plants and plant conditions.
5. Develop a procedure for determining the air content of plastic concrete after placement.
6. Develop guidelines for selecting curing materials and procedures suitable for various mixtures and climatic conditions at the time of paving.
7. Quantify the effects of concrete production techniques and construction used in the field, such as shortened mix times, long hauls as a result of plant location, excess vibration, etc., on the durability of concrete.
8. Develop a method for characterizing the aggregate packing behavior in a concrete mixture based on the aggregate shape and gradation.

- **Pavement Structure**

F. *Pavement Design*

1. Develop innovative pavement designs and construction techniques, such as two-course construction, that optimize the cost and performance of the pavement.

G. *Joints*

1. Determine the conditions under which concrete pavement joints should be sealed or could be designed as an unsealed joint.
2. Evaluate and, if necessary, revise dowel diameter, length and spacing design procedures and guidelines to address not only bearing stresses but also curling/warping stresses and construction curling/warping built into the pavement.
3. Establish new design criteria for allowable bearing between the concrete and dowel.

H. *Reinforcement*

1. Identify reinforcing materials and treatments (steel coatings or treatments, new materials, e.g. polymeric materials) that can perform without corrosion throughout the design life of a long-life pavement.
2. Develop a design method for longitudinal reinforcement that incorporates not only tension due to friction or interlock between the slab and foundation but also bending fatigue resulting from a portion of the load being transferred by the reinforcing steel across cracks and diurnal curling.
3. Develop methods for controlling CRCP crack spacing.

I. *Base*

1. Define the desired rate of drainage required for a pavement based on the structural design, the construction materials used and the environmental conditions.

J. *Drainage system*

1. Replace the saturated flow models currently used when designing pavement drainage systems with models that more accurately characterize water flow through the pavement structure and through the drainage system.
2. Develop guidelines for choosing an appropriate type of base with respect to on-site conditions for each specific project.

K. *Surface*

1. Determine the impact of texturing and surface treatments on tire/pavement interaction relative to safety, noise and comfort for both wet and dry conditions.
2. Develop equipment and a procedure for measuring pavement smoothness directly behind the paving machine.
3. Quantify the effects of aging on surface texture for various aggregate types, gradation and shapes and concrete mixtures.

L. *Concrete pavement modeling*

1. Identify the source or sources responsible for discrepancies between measured and predicted strains. If necessary, develop new models

that more accurately predict pavement response to applied loads and environmental conditions.

2. Develop or investigate alternatives to current fatigue damage models for assessing concrete fatigue life.
3. Develop a model that characterizes water flow through concrete so the stochastic moisture state can be considered while designing the pavement structure and the concrete mix if the regional climatic conditions are known.
4. Incorporate top-down cracking, as well as bottom-up cracking, into design procedures.
5. Calibrate 3-D finite models so that all input parameters, such as interlayer friction, bonding and partial bonding can be incorporated into the design and evaluation procedures based on lab or field measurements. Identify the early and long-term effects of curling and warping on jointed concrete pavements.
6. Develop or extend existing crack prediction models (such as HIPERPAV) to include early age behavior of CRCP and long-term performance of JPCP.
7. Identify the early and long-term effects of curling and warping on concrete pavements.

- **Traffic**

M. Performance prediction

1. Develop algorithms for predicting fatigue life based on load spectra, rather than ESAL's, using data from the LTPP database and/or results from accelerated load testing.

N. Design procedure

1. Develop a rigid pavement performance prediction procedure that can account for changing truck suspensions, tire types, axle configurations, legal load limits and permitted overloads.

2. Extend Pavement Life while Reducing Maintenance Requirements for High-Volume Roadways

Historically, the initial cost of a pavement has had a significant influence on the pavement design selected for construction. An increase in the congestion in urban areas is forcing agencies to look at a longer pavement design life so that once the pavement is constructed (or reconstructed) there is an extended period before traffic is interrupted for maintenance, rehabilitation or reconstruction. This and the inclusion of a user cost when performing life-cycle cost analyses during the pavement selection process has given birth to the need of designing and constructing pavements with extended lives and reduced maintenance requirements. Each component of the pavement must be capable of providing at least 50 years of service. The performance of each component must be considered on an individual basis as well as on how it affects the performance of the pavement system as a whole. Tests and criteria used for measuring the expected performance of each component must be re-evaluated to determine if they are capable of indicating the adequacy of each component within the system for an additional 20 years beyond current pavement design standards. The following items need to be addressed before the design life of the pavement can be extended 20 years or more while reducing required maintenance.

A. *Concrete*

1. Re-evaluate test criteria to determine whether they need to be revised to insure that concrete will perform well for a pavement with an extended design life. Develop alternative test criteria, if necessary. For example, pore structure criteria that are associated with good freeze-thaw durability for a 30-year design life may not be assure adequate durability over a 50-year period. Tests used to assess the concrete materials and the concrete must be performance-related.
2. Identify the parameters required, including air void system requirements, for good freeze-thaw durability in higher strength concrete, which is typically associated with high early strength mixtures used for the reconstruction of high volume urban pavements.
3. Determine the effects of higher strength (which is typically associated with the high early mixtures used for the reconstruction of high volume urban pavements) and associated concrete properties on pavement performance.

B. *Pavement Structure*

1. Identify reinforcing materials and treatments (steel coatings or treatments, new materials, e.g. polymeric materials) that can perform without corrosion throughout the design life of a long-life pavement.
2. Identify the most suitable corrosion resistant materials for manufacturing dowel bars and/or dowel bar coatings. Evaluate the effects of these materials on the pavement system, e.g. possible ASR problems with fiberglass dowels, effects of coating thickness and material stiffness of bar on dowel looseness, etc.
3. Identify the most suitable corrosion resistant materials for manufacturing dowel bars and/or dowel bar coatings. Evaluate the effects of these materials on the pavement system, e.g. possible ASR problems with fiberglass dowels, effects of coating thickness and material stiffness of bar on dowel looseness, etc.
4. Identify base materials that can provide 50 years of life without eroding, thaw weakening, heaving, decreasing in stiffness, or raveling. Develop guidelines for choosing an appropriate type of base with respect to on-site conditions for each specific project.
5. a. Evaluate current pavement drainage system designs and materials to determine whether a 50-year performance life can be obtained.
   b. Identify drainage maintenance program needs for a 50-year design life and determine if these needs could/would be met.
6. Quantify how water flow in both stabilized and unstabilized bases change over the life of the pavement, especially for pavements with an extended design life. Develop analytical models that characterize these changes.

7. Develop a rigid pavement performance prediction procedure that can account for changing truck suspensions, tire types, axle configurations, legal load limits and permitted overloads.
8. Determine whether construction materials meeting current specifications are sufficiently durable and corrosion resistant and will perform adequately when increasing the duration of their exposure to deicing chemicals as a result of increasing the life of the pavement.

3. Reduce the Time Required for Construction, Rehabilitation and Reconstruction

The highway systems are becoming increasingly congested. This has created a need to construct new pavements and maintain, rehabilitate and reconstruct old pavements in a timely fashion so an acceptable level of service can be maintained. Accelerated construction, rehabilitation and reconstruction require the use of rapid setting, durable materials as well as rapid or accelerated test methods to insure the quality of the materials being used. Innovative techniques for expediting the construction process and managing traffic must be continually developed. With the interstate highway system built, much of the future construction will fall in the areas of rehabilitation and reconstruction; thus, rapid methods for measuring pavement performance must be developed for determining optimal pavement management alternative in a systematic fashion based on cost and performance.

Design methods and construction procedures for overlays and repairs must be improved so that rehabilitation is performed quickly and it lasts throughout the expected performance life. Addressing the following items will help accelerate the construction, rehabilitation and reconstruction of concrete pavements while maintaining or extending the designed service life.

- **Construction**

A. Concrete

1. Identify materials that can be used to make concrete that has rapid strength development and is durable, economical and suitable for paving operations.
2. Develop accelerated testing methods for more accurately predicting the long-term strength, durability and performance potential of concrete.
3. Determine the effects of higher strength (which is typically associated with the high early mixes used for the reconstruction of high volume urban pavements) and associated concrete properties on pavement performance.

B. Construction

1. Develop new techniques and equipment that accelerate construction without sacrificing strength, durability, pavement smoothness and other measures of quality.
2. Develop construction-staging techniques that streamline and facilitate the construction process by promoting the rehabilitation of

long pavement segments as oppose to work performed in small clusters of unfocused effort.

- **Rehabilitation**

C. Concrete/mortar/grout

1. Identify concrete, mortar and grout materials and mixes that set and develop strength quickly, are durable, economical and suitable for paving and pavement repair operations.
2. Identify or develop durable, fast-setting and rapid strength developing alternative materials that can be used in place of grout or concrete for partial depth repairs, full depth repairs and dowel retrofits.
3. Develop guidelines for reliably detecting, evaluating and treating material-related distress in concrete.

D. Construction

1. Develop improved equipment and techniques for performing PCC pavement repairs to reduce the time required per repair and improve repair reliability and performance.
2. Develop construction-staging techniques that streamline and facilitate the construction process.
3. Investigate the long-term cost-effectiveness of alternatives to milling out the old pavement under bridges when performing overlays (e.g., utlra-thin whitetopping, bridge jacking or replacing old bridges that have a remaining design-life of less than 10 years).
4. Develop repair guidelines for pcc concrete overlays.

E. Interface between overlay and existing pavement

1. Develop a repeatable test for determining bond strength between pavement layers.
2. *a.* Determine the degree of bonding/debonding required for unbonded overlays or whitetoppings so that a sufficient amount of friction/bond is present to insure that working cracks form at the contraction joints, but so that not enough friction/bond develops to promote the reflection of distresses upward from the existing pavement. Identify surfaces and surface treatments that can meet these requirements.

   b. Determine the degree of bonding/debonding required for bonded overlays and thin/ultra-thin overlays to insure a monolithic behavior throughout the life of the overlay. Identify surfaces and surface treatments that can meet these requirements.
3. Develop models that can predict the degradation of the bond between two paving layers over time and incorporate these models into pavement structural models and overlay design procedures.
4. Update currently available finite element pavement analysis programs to include the ability to model various degrees of bonding or friction between interlayers.

5. Develop a method for modeling reflective cracking using fracture mechanics and crack propagation models and incorporate the methods into concrete overlay design procedures.
6. Characterize the performance and develop a design procedure for whitetopping overlays on heavily loaded pavements.

F. Traffic management

1. Develop techniques for better modeling traffic flow during construction.
2. Develop better traffic management strategies to decrease traffic congestion during construction.

G. Performance

1. More accurately predict the expected life for full- and partial-depth repairs, dowel retrofits and resealed joints based on the pre-existing condition of the repair area and the construction techniques used.
2. Develop a knowledge-based computer program to assist engineers in selecting optimal repair or rehab alternatives and appropriate materials and techniques for performing the work.
3. Develop improved guidelines and procedures for the design and construction of unbonded overlays.

- **Reconstruction**

H. Concrete

1. Identify concrete, mortar and grout materials and mixtures that set quickly, are durable, economical and suitable for paving and pavement repair operations.
2. Develop accelerated testing methods for more accurately predicting the long-term strength, durability and performance potential of concrete.
3. Determine the effects of higher strength (which is typically associated with the high early mixtures used for the reconstruction of high volume urban pavements) and associated concrete properties on pavement performance.

I. Construction

1. Develop new techniques and equipment that accelerate construction without sacrificing strength, durability, pavement smoothness and other measures of quality.
2. Develop reconstruction-staging techniques that streamline and facilitate the construction process.
3. Develop guidelines for selecting strategies for rehabilitating high volume rigid pavements.

J. Traffic management

1. Develop techniques for better modeling traffic flow during reconstruction.
2. Develop better traffic management strategies to decrease traffic congestion during reconstruction.

4. **Increase the Use of Recycling in the Construction of Concrete Pavements**

It is important for the United States to become a more environmentally conscious society by conserving the limited supply of natural resources available and reducing the amount of waste dumped into landfills. This can be done, in part, by incorporating recycling into the construction of highway pavements. Recycling can also be cost effective by reducing aggregate haul distances and replacing portland cement with less expensive by-product mineral admixtures (e.g., fly ash, silica fume, GGBFS,etc). Mineral admixtures can also have a positive impact on the durability of the concrete.

The effects of the recycled material on the design, construction and performance of the concrete pavement must first be evaluated. One must also determine if the standard test and acceptance criteria are appropriate for the recycled material. Appropriate tests or classification systems must be developed if deemed necessary. The following items need further research so that recycling can be achieved without negatively impacting the performance of the pavement.

A. Recycled Concrete Aggregate

1. Develop methods for providing better quality control for the production of recycled concrete aggregate.
2. Identify the effects of using recycled concrete aggregate on the design, construction and performance of concrete pavements.
3. Determine applicability of standard tests and acceptance criteria when applied to using recycled concrete as aggregate and PCC comprised of recycled concrete as aggregate.
4. Identify methods to expedite the pavement break-up and removal process.

B. Pozzolans and Ground Granulated Blast Furnace Slag (GGBFS)

1. Identify desired chemical composition and fineness and improve classification of materials.
2. Develop guidelines for the curing requirements of pavements constructed using concrete mixtures with pozzolans, GGBFS or ternary blends to insure that adequate strength and durability are developed before placing the system in service or exposure conditions.
3. Evaluate and compare the costs, risks and benefits associated with the use of pozzolans, GGBFS and ternary mixtures.
4. Develop a test to be used for classifying mineral admixtures according to their ability to reduce or increase the ASR potential of a mix.
5. Characterize interactions between pozzolans, GGBFS and cementitious materials and develop rapid, field applicable test to demonstrate compatibility.

5. Improve and Quantify the Quality Control/Assurance Process for Concrete Pavement Construction

Reliability-based design procedures require knowledge of the sources and magnitude of performance variability constructed into the pavement system, as well as the sources of performance variability that occur throughout the life of the pavement. It is also important to quantify the differences between the designed structure and the as-built structure and to recognize these differences as potential sources of long-term deviations from the designed level of performance. The following items need to be addressed for the development of efficient reliability-based design procedures.

A. Quality assessment

1. Quantify typical differences between designed and as-built pavement structures and identify the effects of these differences on pavement performance variability.

2. Quantify the influence of production and construction techniques on the difference between designed and as-built pavement structures.

3. Quantify the relationship between the cost of construction vs. quality of construction.

B. Variability

1. Quantify the variability that occurs in construction and in construction materials between projects and within projects and the effect the construction variability has on performance variability.

2. Quantify long-term and short-term (daily and seasonal) variability for design input parameters and relate this to performance variability.

6. Implement the Tools and Methodologies Necessary for Making More Cost-Effective Decisions

There are many methods for improving the performance of concrete pavements. It is important that only the most cost-effective improvements are implemented by insuring that the increase in cost associated with a given improvement can be justified by the resulting increase in performance. Costs that need to be considered include engineering, construction and user (delay times and vehicle operating costs) costs. The other aspect that must be addressed is estimating the increase in performance life that can be attributed to each specific improvement. The following items need to be addressed before fiscally responsible decisions can be made based on costs, performance life and valid discount rates.

A. Construction, maintenance, rehabilitation and reconstruction

1. Improve the formalized processes available for quantifying delay times and vehicle operator costs (including fuel consumption) for project-level analyses so that they are implementable. The resulting user costs can then be incorporated into pavement management decisions based on life-cycle cost analyses.

2. Identify and characterize relationships between the cost of various components of concrete pavements and the effect of these components on increasing pavement life.

3. Identify and characterize relationships between the cost of various rehabilitation and maintenance alternatives and their effect on increasing the life of the pavement.
4. Determine the appropriateness of using discount rates for public projects since all allocated money will be spent.
5. Develop more accurate performance prediction models that can be used for making more timely rehabilitation decisions, for the development of performance related specifications, and for pavement preservation/preventive maintenance decisions.

APPENDIX B

Table of Research Needs Categorized by Topic

Table 1. Categorizing and Prioritizing Research Needs

(12-10-00)

Color Code

IPRF or FHWA identified a similar research need.
Research needs taken from IPRFF Action Plan.
Research funded by either FHWA or IPRF relating to the research need identified.
Research recently funded by agencies other than FHWA or IPRF relating to the research need identified.

Research Need (Associated Goal)	Level of Priority-1, 2 or 3 (Year Funded)	Preliminary Research Required	Related Research Funding Organization/Performing Organization: "Title of Project" (Completion date)	Comments
1. Cement				
a. Identify the effects of the chemical composition and fineness of cements on the mixture and improve classification of cements. ***(Goal 1)***	1 (2002)	NCHRP 18-5 (7/'00)	IPRF/ CTL: "Task 4- Tests or Standards to Identify Compatible Combinations of Individually Acceptable Concrete Materials" (4/'03) NCHRP 18-5/Penn. State Univ.: "Relation of Portland Cement Characteristics to Concrete Durability" (7/'00) NIST/NIST: "Rietveld XRD Analysis of Clinker and Cement: A Research and Wuality Control Tool" (on-going)	
b. Develop a method for determining the permissible alkali content based on the type of aggregate and the mixture that will be used. ***(Goal 1)***	2 (2004)			
2. Pozzolans, Ground Granulated Blast Furnace Slag (GRBFS) and Blended Cements				
a. Identify the effects of the chemical composition and fineness and improve classification of materials. ***(Goal 4)***	2 (2003)		IPRF/CTL: "Task 4- Tests or Standards to Identify Compatible Combinations of Individually Acceptable Concrete Materials" (4/'03) NCHRP 18-3/CTL: "Silica Fume Concrete Bridge Decks" (3/'95) NCHRP 18-3/Pending: "Supplementary Cementitious Materials to Enhance Durability of Concrete Bridge Decks" (Pending)	
b. Evaluate and compare the cost, benefits and risks associated with the use of pozzolans, GGBFS and ternary mixtures. ***(Goal 4)***	1 (2002)		NIST/NIST: "Economics (life-cycle cost) of HPC Structures" (on-going) NCHRP 18-3/CTL: "Silica Fume Concrete Bridge Decks" (3/'95) NCHRP 18-3/Pending: "Supplementary Cementitious Materials to Enhance Durability of Concrete Bridge Decks" (Pending)	
c. Develop guidelines for the curing requirements of pavements constructed using concrete mixtures with pozzolans, GGBFS or ternary blends to ensure that adequate strength and durability are developed before placing the system in service or exposure conditions. ***(Goal 4)***	1 (2004)	FHWA Project 14 (8/'01)	FHWA/FHWA & W.E.S.: "Project 14 - Performance of PCC Curing Materials and Procedures" (8/'01) NIST/NIST: "Curing of High-Performance Concrete" (on-going) NCHRP 18-3/CTL: "Silica Fume Concrete Bridge Decks" (3/'95) NCHRP 18-3/Pending: "Supplementary Cementitious Materials to Enhance Durability of Concrete Bridge Decks" (Pending)	If FHWA Project 14 does not address the use of mineral admixtures, then it may have little relevance to research need 2.c.
d. Characterize the interactions between pozzzolans, GGBFS and cementitious materials and develop rapid, field applicable test to demonstrate compatibility. ***(Goal 4)***	1 (2002)			

e. Develop a test to be used for classifying mineral admixtures according to their ability to reduce or increase the ASR potential of a mix. ***(Goal 4)***	1 (2003)			
3. Chemical Admixtures				
a. Characterize interactions between admixtures and cementitious materials and develop rapid, field applicable test to demonstrate compatibility. ***(Goal 1)***	1 (2005)	IPRF Task 4 (4/'03)	IPRF/ CTL: "Task 4- Tests or Standards to Identify Compatible Combinations of Individually Acceptable Concrete Materials" (4/'03)	
4. Aggregate				
a. Develop a procedure for identifying the most cost-effective aggregate source for a construction project based on the cost of the material, which includes consideration of haul distances, the quality of the material, needed mix design adjustments, and projected long-term PCC performance. ***(Goal 1)***	3 (2006)			
b. Develop guidelines for detecting, evaluating and treating material-related distress in concrete pavements. ***(Goal 4)***	2 (2003)	FHWA Project 22 (8/'00) FHWA Project 21 (10/'99)	FHWA/FHWA & Univ. of New Hampshire: "Project 22 - Residual ASR in Existing PCC, and Potential for Recycling and Repair" (8/'00) FHWA/Mich. Tech. Univ.: "Project 21 - Detection, Analysis And Treatment of Materials Related Distress in PCC Pavements" (10/'99)	
c. Develop new techniques for obtaining good performance from lower quality aggregates that may be available locally for use in PCC. ***(Goal 1)***	2 (2004)		National Research Council of Canada/National Research Council of Canada, V.S. Ramachandran: "Alkali-Aggregate Expansion Reducing Admixtures" ('99) New Mexico SH&TD & FHWA/New Mexico SH&TD: "Evaluation of Low Strength Problems with Lithium Additive" (6/'99)	
d. Develop test that can identify durable aggregates before the quarry wall is mined. ***(Goal 1)***	3 (2008)			
e. Develop methods for providing better quality control for the production of recycled concrete as aggregate. ***(Goal 4)***	2 (2006)			
f. Identify the effects of using recycled concrete as aggregate on the design, construction and performance of concrete pavements. ***(Goal 4)***	2 (2006)	FHWA Project 5 (5/'00)	FHWA/Univ. of Minnesota: "Project 5 - Physical and Mechanical Properties of Recycled PCC Aggregate Concrete" (5/'00) ICAR/Pending: "Criteria for use of Recycled Materials with Natural Aggregates in Mixtures and Unbound Applications" (Pending)	
g. Determine applicability of standard tests and acceptance criteria when applied to using recycled concrete as aggregate and PCC comprised of recycled concrete as aggregate. ***(Goal 4)***	2 (2004)	FHWA Project 5 (5/'00)	FHWA/Univ. of Minnesota: "Project 5 - Physical and Mechanical Properties of Recycled PCC Aggregate Concrete" (5/'00)	

h. Develop a procedure that uses test methods that characterize the quality and durability of an aggregate to identify pavement and mix design components needed to optimize the performance of the pavement. ***(Goal 1)***	1 (Pending)	NCHRP 4-20C (Pending)	NCHRP 4-20/Texas A&M, 4-20A/Richard Meininger, 4-20B & 4-20C/Pending: "Aggregate Tests That Relate to Performance of PCC Pavements" (Pending)	
i. Identify procedures that can be taken to protect existing aggregate sources from urban development and to access sources that are currently difficult to retrieve because of environmental concerns and/or the presence of existing urban development. ***(Goal 1)***	1 (2002)			
5. Water-to Cementitious Ratio				
a. Develop a systematic approach to determine the optimum w/c and permeability for each project based on the relationship between cost, constructability and durability. ***(Goal 1)***	1 (2005)	Research Need 5.b Research Need 5.c		
b. Provide guidelines for determining the w/c required to improve the performance of an aggregate source based on the durability of the aggregate. ***(Goal 1)***	1 (2001)			
c. Define the lower envelope of w/c's that can be used without excessive micro-cracking or self-desiccation occurring when considering the climatic conditions during paving and the curing techniques utilized. ***(Goal 1)***	1 (2001)			
d. Develop a quick, reliable test procedure to determine the water-cement ratio immediately before concrete placement. ***(Goal 1)***	2 (2005)			
6. Concrete Mixes				
a. Re-evaluate test criteria to determine whether they need to be revised to insure that concrete will perform well for 50 years. Develop alternative test criteria, if necessary. For example, pore structure criteria that are associated with good freeze-thaw durability for a 30-year design life may not assure adequate durability over a 50 year period. Tests used to assess the concrete materials and the concrete must be performance-related. ***(Goal 1)***	1 (2002)		NCHRP 18-9/CTL: "Guidelines for Reducing the Premature Deterioration of Hydraulic Cement Concrete Pavements" (3/'01) NCHRP 18-5/Penn. State Univ.: "Relation of Port Cement Characteristics to Concrete Durability" (7/'00)	
b. Identify the parameters required, including air void system requirements, for good freeze-thaw durability in higher strength concrete, which is typically associated with high early strength mixtures used for the reconstruction of high volume urban pavements. ***(Goal 1)***	1 (2002)	FHWA Project 3 (12/'00)	FHWA/FHWA: "Project 3 – Freeze-Thaw Resistance of Concrete with Marginal Entrained Air Content" (12/'00)	

c. Determine the effects of higher strength (which is typically associated with the high early mixes used for the reconstruction of high volume urban pavements) and associated concrete properties on pavement performance. ***(Goal 2 & 3)***	2 (2004)	FHWA Project 19 (5/'00)	FHWA/Univ. of Mich.: "Project 19 - The Effects of Higher Strength and Associated Concrete Properties on Pavement Performance" (5/'00) NCHRP 18-4A/Texas A&M: "Durability of "Early-Opening-to-Traffic" PCC for Pavement Rehabilitation" (9/'98) NCHRP 18-4B/Mich. Tech. Univ.: (4/'02)	
d. Determine the cause of the durability-related premature deterioration problems currently being encountered. ***(Goal 1)***	1 (2001)	NCHRP 18-9 (3/'01)	NCHRP 18-9/CTL: "Guidelines for Reducing the Premature Deterioration of Hydraulic Cement Concrete Pavements" (3/'01))	
e. Develop modified or improved methods of rapid and reliable testing and assessing the damage of freeze-thaw test specimens, building upon findings from a previous SHRP (C203) study. ***(Goal 1)***	1 (2002)	FHWA Project 3 (12/'00)	FHWA/FHWA: "Project 3 – Freeze-Thaw Resistance of Concrete with Marginal Entrained Air Content" (12/'00)	
f. Define adjustments required to take a mix design from the lab to the field. This would include quantifying the effects of mix times for various types of plants and plant conditions. ***(Goal 1)***	1 (2001)			
g. Develop a mechanistic approach for designing concrete mixes. Desired fresh concrete properties and hardened concrete properties will be the design objectives, which would be selected based on the pavement design, the construction techniques to be utilized and both the construction and long-term environmental conditions. The output should include types and quantities of materials, the order in which the materials should be combined and required mix times. ***(Goal 1)***	3 (2010)	Research Need 2.d Research Need 4.a Research Need 4.h Research Need 5.a Research Need 5.b Research Need 5.c NIST HYPERCON (2002)	FHWA/FHWA & NIST: "Project 7 - Concrete Mixture Optimization Using Statistical Methods" (3/'00) NIST/NIST: "Development of a Computer-Integrated Knowledge System (HYPERCON)" (2002)	
h. Develop a cost-effective procedure for determining the air content of plastic concrete after placement. ***(Goal 1)***	2 (2005)		SHRP C-204 "Evaluating the Use of Fiber-Optics to Measure the Air Content in Fresh Concrete" (10/'90) SHRP C-204 "Evaluation of Danish Air Meter" (10/'90) FHWA/FHWA: "Project 25- Determine the Accuracy and Cost-Effectiveness of Using the Danish Test for Measuring Air Content of Plastic Concrete" (on-going)	
i. Develop guidelines for selecting curing materials and procedures suitable for various mixes and climatic conditions at the time of paving. ***(Goal 1)***	1 (2004)	FHWA Project 14 (8/'01)	FHWA/FHWA & W.E.S.: "Project 14 - Performance of PCC Curing Materials and Procedures" (8/'01) NIST/NIST: "Curing of High-Performance Concrete" (on-going)	
j. Develop accelerated testing methods for more accurately predicting the long-term durability and performance potential of concrete so that mix changes made in the field do not detrimentally affect the performance of the pavement. ***(Goal 3)***	3 (2006)		FHWA/FHWA: "Project 1 – Predictive Approach for Long-Term Performance Using Accelerated Aging" (4/'02)	Research need 6.k refers to the accelerated tests that can be used in the field and FHWA Project 1 is for accelerated testing after the concrete has cured.

k. Identify concrete, mortar and grout materials and mixes that have rapid strength development, are economical and are suitable for paving and pavement repair operations. ***(Goal 3)***	3 (2007)		NCHRP 18-4A/Texas A&M: "Durability of "Early-Opening-to-Traffic" PCC for Pavement Rehabilitation" (9/'98) NCHRP 18-4B/Mich. Tech. Univ.: (4/'02) FHWA/CALTRANS: "SP-204-Design and Construction Guidelines for Load Transfer Restoration" ('98)	The completion of NCHRP 18-4B will help to identify durable concrete repair mixes. Concurrent research can be performed on mortar and grout materials.
l. Identify and develop guidelines for the use of *durable*, fast-setting alternative materials that can be used in place of grout or concrete for partial depth repairs, full depth repairs and dowel retrofits. ***(Goal 3)***	3 (2006)		FHWA/CALTRANS: "SP-204-Design and Construction Guidelines for Load Transfer Restoration" ('98)	The report FHWA-SA-98-047 discusses the design and construction guidelines for retrofitting load transfer devices.
m. Develop a test procedure or revise currently available procedures capable of rapidly determining the ASR potential of *concrete mixtures*. ***(Goal 1)***	2 (2003)	FHWA Project 2 (12/'00) ICAR Project 301 (1/'01)	FHWA/FHWA: "Project 2 – Development of a Mix-Specific ASR Test Method" (12/'00) ICAR/David Fowler: "Project 301 - Alkali-Silica Reaction in Portland Cement Concrete" (1/'01)	
n. Develop a method for characterizing the aggregate packing behavior in a concrete mixture based on the aggregate shape and gradation. ***(Goal 1)***	1 (2002)		ICAR/David Fowler, David Whitney, Barry Hudson & Joe Allen: "Project 104 – Effects of Aggregate Characteristics on the Performance of Portland Cement Concrete" (9/'02) NIST/NIST: "Flow Properties of Fresh High-Performance Concrete" (on-going)	
o. Quantify the effects of concrete production techniques and construction used in the field, such as shortened mix times, long hauls as a result of plant location, excess vibration, etc., on the durability of concrete. ***(Goal 1)***	1 (2003)			
7. Pavement Design				
a. Develop innovative pavement designs and construction techniques, such as two-course construction, that optimize the cost and performance of the pavement. ***(Goal 1)***	3 (2008)		Michigan DOT/Michigan DOT: "Demonstration Project on Two-Course Construction" FHWA/APTech: "Summary of TE-30 Projects (High Performance Rigid Pavements)" (12/'00)	Wisconsin DOT, Kansas DOT and the University of New Hampshire all have TE-30 projects related to research need 7.a.
8. Joints				
a. Determine the conditions under which concrete pavement joints should be sealed or could be designed as an unsealed joint. ***(Goal 1)***	1 (Pending)	IPRF Task 9 (Pending)	IPRF/Pending: "Task 9 - Influence of Sealing Transverse Contraction Joints on the Overall Performance of Concrete Pavements" (Pending) NCHRP 20-50(2)/ Katie Hall: "LTPP-Relative Performance of JPCP with Sealed and Unsealed Joints" (10/'00) FHWA/APTech: "Summary of TE-30 Projects (High Performance Rigid Pavements)" (12/'00)	Additional studies should be performed along with NCHRP 20-50(2) so a broader range of pavement designs and concrete mixes can be considered.
b. Identify the most suitable corrosion resistant materials for manufacturing dowel bars and/or dowel bar coatings. Evaluate the effects of these materials on the pavement system, e.g. possible ASR problems with fiberglass dowels, effects of coating thickness and material stiffness of bar on dowel looseness, etc. ***(Goal 1)***	1 (2002)		Arkansas SH&TD/Univ. of Arkansas "Design Properties of Fiber Reinforced Bars" (4/'94) NCHRP 10-37C/Concorr: "Repair and Rehab. of Bridge Components Containing Epoxy-Coated Reinforcement" (12/'00) ISIS Canada/University of Manitoba: "Fiber Reinforced Polymer Dowels for Concrete Pavements" (4/'99) MDA/HITEC: "Fiber Reinforced Polymer Dowel bars and Stainless Steel Dowel Bars" ('99)	

c. Evaluate and, if necessary, revise dowel diameter, length and spacing design procedures and guidelines to address not only bearing stresses but also curling/warping stresses and construction curling/warping built into the pavement. ***(Goal 1)***	1 (2001)		University of Maine: "3-D Finite Element Study on Load Transfer at Doweled Joints in Flat and Curled Rigid Pavements" (10/'00)	
d. Establish design criterion for allowable bearing stress between the concrete and dowel. ***(Goal 1)***	1 (2005)	Research Need 8.c		
9. Reinforcement				
a. Identify reinforcing materials and treatments (steel coatings or treatments, new materials, e.g. polymeric materials) that can perform without corrosion throughout the design life of a long-life pavement. ***(Goal 2)***	2 (2003)		NCHRP/Man-Tech Development Inc.: "Aluminum Bronze Alloy for Corrosion Resistant Rebar" (8/'96) NCHRP (10-37A),/Florida Atlantic Univ.: "Performance of Epoxy-coated Reinforcing Steel-Laboratory Testing" (12/'00)	
b. Develop a design method for longitudinal reinforcement that incorporates not only tension due to friction or interlock between the slab and foundation but also bending fatigue resulting from a portion of the load being transferred by the reinforcing steel across cracks and diurnal curling. ***(Goal 1)***	1 (2001)			
c. Develop methods for controlling CRCP crack spacing. ***(Goal 1)***	1 (2001)		FHWA/ Transtec: "Project 16 - Computer-Based Guidelines for Concrete Pavements" (12/'03) FHWA/PCS Law: "Performance of Continuously Reinforced Concrete Pavements" (10/'98)	
10. Base				
a. Identify base materials that can provide an extended life without eroding, thaw weakening, heaving, decreasing in stiffness, or raveling and re-evaluate the applicability of current test criteria for a 50 year design life. ***(Goal 2)***	3 (2006)		NCHRP 4-23A/ARA: "Aggregate Tests Related to Performance of Unbound Pavement Layers" (12/'99) PCA/CTL: "Evaluation of Cement Treated Bases and Subbases Under PCC Pavement" (unknown) FHWA/APTech: "Summary of TE-30 Projects (High Performance Rigid Pavements)" (12/'00)	
b. Develop guidelines for choosing an appropriate type of base with respect to on-site conditions for each specific project. ***(Goal 1)***	2 (2005)			

11. Drainage Systems				
a.1. Evaluate current pavement drainage system designs and materials to determine whether a 50-year performance life can be obtained. ***(Goal 2)*** 2. Identify drainage maintenance program needs for a 50-year design life and determine if these needs could/would be met. ***(Goal 2)***	2 (2004)	NCHRP 1-34C (4/'01)	NCHRP 1-34C/K. Hall: " Effects of Subsurface Drainage on Asphalt and PCC Pavements" (4/'01) NCHRP 1-34B/K. Hall: "Effectiveness of Subsurface Drainage for HMA and PCC Pavements" (11/'99) NCHRP 1-34/ERES: "Perform. of Subsurface Pave. Drain" (3/'98) NCHRP Synth. 239: "Pave. Subsurface Drain. Systems" (4/'97) NCHRP Synth. 285: "Maintenance of Edgedrains" (7/'00)	
b. Replace the saturated flow models currently used when designing pavement drainage systems with models that more accurately characterize water flow through the pavement structure and through the drainage system. ***(Goal 1)***	2 (2005)			
c. Quantify how water flow in both stabilized and unstabilized bases change over the life of the pavement, especially for pavements with an extended design life. Develop analytical models that characterize these changes. ***(Goal 2)***	2 (2003)			
d. Define the desired rate of drainage required for a pavement based on the structural design, the construction materials used and the environmental conditions. ***(Goal 1)***	1 (2003)			
12. Surface Texture				
a. Determine the impact of texturing and surface treatments on tire/pavement interaction relative to safety, noise and comfort for both wet and dry conditions. ***(Goal 1)***	2 (2005)	IPRF Task 2 (3/'04)	IPRF/Pending: "Task 2.-Impact of Surface Texturing on Reducing Wet-Weather Accidents." (3/'04)	
b. Develop equipment and a procedure for measuring pavement smoothness directly behind the paving machine. ***(Goal 1)***	3 (2007)			
c. Quantify the effects of aging on surface texture for various aggregate types, gradations and shapes and concrete mixtures. ***(Goal 1)***	2 (2006)		ICAR/Pending: "Criteria for use of Recycled Materials with Natural Aggregates in Mixtures and Unbound Applications" (Pending)	
13. Modeling				
a. Identify the source or sources responsible for discrepancies between measured and predicted strains. If necessary, develop new models that more accurately predict pavement response to applied loads and environmental conditions. ***(Goal 1)***	1 (2005)	Research Need 13.c Research Need 16.a	FAA/FAA: "Three-Dimensional Finite Element Modeling of Portland Cement Concrete Airport Pavements" (4/'99)	
b. Develop or investigate alternatives to current fatigue damage models for assessing concrete fatigue life. ***(Goal 1)***	1 (2001)			

c. Calibrate 3-D finite models so that all input parameters, such as interlayer friction bonding and partial bonding can be incorporated into the design and evaluation procedures based on lab or field measurements. ***(Goal 1)***	1 (2004)	Research Need 16.a	FAA/Galaxy Scientific: "Pavement Joint and Interface Behavior at the FAA Test Site at Denver Airport" (4/'99) FAA/Univ. Illinois, at Urbana-Champaign: "Response of Rigid Pavements Under Temperature Differential" (2/'99) FAA/FAA: "Three-Dimensional Finite Element Modeling of Portland Cement Concrete Airport Pavements" (4/'99)	
d. Incorporate top-down cracking, as well as bottom-up cracking, into design procedures. ***(Goal 1)***	1 (2001)		NCHRP 1-37A/ERES: "Development of the 2002 Guide for the Design of New and Rehabilitation Pavements Structure" (12/'01)	
e. Develop a model that characterizes water flow through concrete so the stochastic moisture state can be considered while designing the pavement structure and the concrete mix if the regional climatic conditions are known. ***(Goal 1)***	3 (2006)		NIST/NIST: "Simulation of the Performance and service Life of High Performance Concrete" (on-going) NIST/NIST: "Development of New Lab Procedures and Equipment to Measure Moisture in PCC" (on-going)	
f. Develop or extend existing crack prediction models (such as HYPERPAVE) to include early age behavior of CRCP and long-term performance of JPCP. ***(Goal 1)***	2 (2007)	FHWA Project 16 (1/03)	FHWA/Transtec: "Project 16.-"Computer-Based Guidelines for Concrete Pavements" (1/'03)	
14. Traffic				
a. Develop algorithms for predicting fatigue life based on load spectra, rather than ESAL's, using data from the LTPP database and/or results from accelerated load testing. ***(Goal 1)***	3 (2007)	NCHRP 1-37A (4/'02)	NCHRP 1-37A/ERES: "Development of the 2002 Guide for the Design of New and Rehabilitation Pavements Structure" (12/'01)	
b. Develop a rigid pavement performance prediction procedure that can account for changing truck suspensions, tire types, axle configurations, legal load limits and permitted overloads. ***(Goal 1 & 2)***	2 (2003)	NCHRP 1-37A (4/'02) Mn/DOT (9/'00)	NCHRP 1-37A/ERES: "Development of the 2002 Guide for the Design of New and Rehab. Pavement Structure" (12/'01) MnDOT/Univ. Minnesota: "Development of Vehicle Load Damage Factors for Rigid Pave." (9/'00)	
c. Develop techniques for better modeling traffic flow during rehabilitation and reconstruction. ***(Goal 3)***	2 (2003)			
d. Develop better traffic management strategies to decrease traffic congestion during reconstruction, rehabilitation and maintenance. ***(Goal 3)***	2 (2007)	Research Need 14.c	IPRF/Texas Transportation Institute: "Task 1.-Traffic Management Optimization Studies for Reconstructing High-Vol. Roadways" (3/'04) NCHRP 10-50A/Texax A&M: "Guidelines for Selecting Strategies for Rehab. Rigid Pave. Subjected to High-Traffic Volumes" (11/'00)	Concurrent research can be performed along with IPRF Task 1 and NCHRP 10-50A to develop better traffic management strategies for decreasing congestion during maintenance since the scopes of Task 1 and NCHRP 10-50A are restricted to reconstruction and rehabilitation, respectively.

15. Environmental				
a. Determine whether construction materials meeting current specifications are sufficiently durable and corrosion resistant and will perform adequately when increasing the duration of their exposure to deicing chemicals as a result of increasing the life of the pavement by 20 years. ***(Goal 2)***	2 (2003)			
b. Identify the early and long-term effects of curling and warping on concrete pavements. ***(Goal 1)***	1 (2002)	FHWA Project 20 (9/'00)	FHWA/Univ. of Washington: "Project 20 - Identify the Early and Long-Term Effects of Curling and Warping on Jointed concrete pavements" (9/'00) FAA/Galaxy Scientific: "Effects of Slab Size on Airport Pavement Performance" (4/'00) FAA/Univ. Illinois, at Urbana-Champaign: "Response of Rigid Pavements Under Temperature Differential" (2/'99)	
16. Overlays				
a. Develop a repeatable test for determining bond strength between pavement layers. ***(Goal 3)***	1 (2001)		FHWA/Mark Sprinkel: "Summary of the Field Performance of Thin Bonded Overlays and Surface Laminates" ('99)	
b. 1. Determine the degree of bonding/debonding required for unbonded overlays or whitetoppings so that a sufficient amount of friction/bond is present to insure that working cracks form at the contraction joints, but so that not enough friction/bond develops to promote the reflection of distresses upward from the existing pavement. Identify surfaces and surface treatments that can meet these requirements. ***(Goal 3)*** 2. Determine the degree of bonding/debonding required for bonded overlays and thin/ultra-thin overlays to insure a monolithic behavior throughout the life of the overlay. Identify surfaces and surface treatments that can meet these requirements. ***(Goal 3)***	1 (2004)	Research Need 16.a	IPRF/Pending.: "Task 8- Performance and Design of Separated (Unbounded) Concrete Overlays" (Pending) FHWA/Mark Sprinkel: "Summary of the Field Performance of Thin Bonded Overlays and Surface Laminates" ('99)	
c. Characterize the performance and develop a design procedure for whitetopping overlays on heavily loaded pavements. ***(Goal 3)***	2 (2006)	IPRF Task 3 (3/'04) FHWA & Mn/DOT (12/'01) IPRF Task 5 ('00)	IPRF/Transtec: " Task 3-Performance and Design of Whitetopping on Heavily Trafficed Roadways" (3/'04) PCA/CTL: "Analysis and Design of Whitetopping and Ultra-thin Whitetopping Pave.-Colorado Project" ('97) FHWA & Mn/DOT/Mn/DOT: "Calibrating Design Procedures for Thin- and Ultra-Thin Whitetopping Using Measured Field Strains and Finite Element Modeling" (12/'01) IPRF & FHWA/FHWA: " Task 5-Accelerated Loading Tests for Ultra-Thin Whitetopping" ('00)	

d. Update currently available finite element pavement analysis programs to include the ability to model various degrees of bonding or friction between interlayers. ***(Goal 3)***	1 (2000)	IPRF Task 10 ('00)	IPRF/ERES: "Task 10- Revision of ISLAB 2000 for Subbase/Pavement Interaction" ('00)	
e. Develop a method for modeling reflective cracking using fracture mechanics and crack propagation models and incorporate the method into overlay design procedures. ***(Goal 3)***	2 (2003)			
f. Develop improved guidelines and procedures for the design and construction of unbonded overlays. ***(Goal 3)***	2 (Pending)	Research Need 16.a Research Need 16.b IPRF Task 8 (Pending)	NCHRP 10-41/ERES: "Evaluation of Unbonded Portland Cement Concrete Overlays" (4/'97) IPRF/Pending: "Task 8- Performance and Design of Separtated (Unbounded) Concrete Overlays" (Pending)	
g. Develop models that can predict the degradation of the bond between two paving layers over time and incorporate these models into pavement structural models and overlay design procedures. ***(Goal 3)***	2 (2005)	Research Need 16.a		
17. Maintenance/Rehabilitation/ Reconstruction/Construction				
a. Develop new techniques and equipment that accelerate construction without sacrificing strength, durability, pavement smoothness and other measures of quality. ***(Goal 2)***	2 (2006)		FHWA/Univ. of Texas: "Project 23 - Precast Slabs for Pave. Rehab." (1/'00)	
b. Develop construction- staging techniques that streamline and facilitate the reconstruction/rehabilitation/maintenance process by promoting the rehabilitation of long pavement segments as oppose to work performed in small clusters of unfocused effort. ***(Goal 3)***	2 (2006)		IPRF/Texas Transportation Institute: "Task 1.-Traffic Management Optimization Studies for Reconstructing High-Vol. Roadways" (3/'04) NCHRP 10-50A/Texas A&M: "Guidelines for Selecting Strategies for Rehabilitating Rigid Pavements Subjected to High-Traffic Volumes" (11/'00)	
c. Develop improved equipment and techniques for performing PCC pavement repairs to reduce the time required per repair and improve repair reliability and performance. ***(Goal 3)***	1 (2002)		FHWA SP 204 "Retrofit Load Transfer" ('98)	The following reports were produced under this research effort: FHWA-SA-97-103 FHWA-SA-98-031 FHWA-SA-98-047
d. Investigate the long-term cost-effectiveness of alternatives to milling out the old pavement under bridges when performing overlays (e.g., ultra-thin whitetopping, bridge jacking or replacing old bridges that have a remaining design-life of less than 10 years). ***(Goal 3)***	3 (2007)			
e. Develop repair guidelines for pcc concrete overlays. ***(Goal 3)***	2 (2004)	IPRF ('00) IPRF Task 5 ('00)	IPRF/CTL: "Develop Repair Guidelines for Ultra-Thin and Thin Whitetopping" ('00) IPRF & FHWA/FHWA: "Task 5-Accelerated Loading Tests for Ultra-Thin Whitetopping" ('00)	

f. Develop a knowledge-based computer program to assist engineers in selecting optimal repair or rehab alternatives and appropriate materials and techniques for performing the work. ***(Goal 3)***	2 (2005)	Research Need 17.h FHWA Project 24 (1/'03) NCHRP 1-38 (9/'03) NCHRP 10-50A (11/'00) NCHRP 20-50 (3/4)(7/'01)	FHWA/Texas A & M, CTL & APTech: "Project 24 – Repair and Rehabilitation Materials and Techniques for PCC Pavements" (1/'03) NCHRP 1-38/K. Hall: "Guide on Pave. Rehab. Strategies" (9/'00) NCHRP 10-50/Nichols Consult. Engineers: "Strategies for Rehab. Rigid Pave. Subjected to High-Traffic Volumes" (6/'98) NCHRP 10-50A/Texax A&M: "Guidelines for Selecting Strategies for Rehab. Rigid Pave. Subjected to High-Traffic Volumes" (11/'00) NCHRP 20-50(3/4)/ K. Hall: "LTPP –Effectiveness of Maintenance and Rehabilitation Options" (7/'01)	
g. Identify methods to expedite the pavement break-up and removal process. ***(Goal 3 & 4)***	3 (2007)			
h. More accurately predict the expected life for full- and partial-depth repairs, dowel retrofits and resealed joints based on the pre-existing condition of the repair area and the construction techniques used. ***(Goal 3)***	1 (2003)	NCHRP 20-50 (3/4) (7/'01)	NCHRP 20-50(3/4)/ K. Hall: "LTPP –Effectiveness of Maintenance and Rehabilitation Options" (7/'01) NCHRP 1-38/ K. Hall: "Guide on Rehabilitation Strategies" (10/'00) FHWA/BRE: "Rehabilitation Performance Trends: Early Observations from Long-Term Pavement Performance Specific Pavement Studies (1/'98) FHWA SP 205 "Quality Concrete Pavement Rehabilitation and Preservation" ('99)	Concurrent research can be performed on resealing joints because this was not included in the LTPP study.
18. Quality Control/Assurance				
a. Quantify typical differences between designed and as-built pavement structures and identify the effects of these differences on pavement performance variability. ***(Goal 5)***	1 (2003)	NCHRP 20-50 (05) (7/'01)	NCHRP 20-50 (05)/Consulpav International: "LTPP-Long-Term Variations in Pavement Design Inputs" (7/'01) Improved Prediction Models for PCC Pavement Performance-Related Specifications Vol. I (FHWA-RD-00-130) and Vol. II (FHWA-RD-00-131) Guide to Developing Performance-Related Specifications for PCC Pavements Vol. I (FHWA-RD-98-155), Vol. II (FHWA-RD-98-156), Vol. III (FHWA-RD-98-171) and Vol. IV (FHWA-RD-99-059) Performance-Related Specifications for Concrete Pavements Vol. I (FHWA-RD-93-042), Vol. II (FHWA-RD-93-043) and Vol. III (FHWA-RD-93-044)	
b. Quantify the variability that occurs in construction and in construction materials between projects and within projects and the effect the construction variability has on performance variability. ***(Goal 5)***	1 (2001)		NCHRP Synthesis 232/C. Hughes: "Variability in Highway Pavement Construction" ('96) NCHRP 20-50 (05)/Consulpav International: "LTPP-Long-Term Variations in Pavement Design Inputs" (7/'01) FHWA/APTech: "Summary of TE-30 Projects (High Performance Rigid Pavements)" (12/'00)	NCHRP 20-50 (05) considers only within project variability. Concurrent research can be performed that looks at variability in construction and construction materials from project to project.
c. Quantify long-term and short-term (daily and seasonal) variability for design input parameters and relate this to performance variability. ***(Goal 5)***	1 (2004)	NCHRP 20-50 (07/12) (1/'02) NCHRP 20-50 (05) (7/'01)	NCHRP 20-50 (07/12)/Univ. of Tennessee: "LTPP-Daily and Seasonal Variations in Insitu Material Properties" (1/'02) NCHRP 20-50 (05)/Consulpav International: "LTPP-Long-Term Variations in Pavement Design Inputs" (7/'01)	

d. Quantify the relationship between the cost of construction versus the qualtity of construction. ***(Goal 5)***	2 (2006)			
e. Quantify the influence of production and construction techniques on the difference between designed and as-built pavement structures. ***(Goal 5)***	1 (2003)			
19. Costs				
a. Improve the formalized processes available for quantifying delay times and vehicle operator costs (including fuel consumption) for project-level analyses so that they are implementable. The resulting user costs can then be incorporated into pavement management decisions based on life-cycle cost analyses. ***(Goal 6)***	3 (2007)		NCHRP 27-12/Hickling Lewis Brod, Inc.: "Synth. of Info. Related to High. Problems-User and Mitigation Costs in High. Proj." (9/'97) NCHRP 1-33/Wash. State. Univ.: "Methodology to Improve Pave. Invest. Decisions" (1/'00) FHWA/FHWA: "Life-Cycle cost Analysis in Pavement Design" (9/'98)	
b. Identify and characterize relationships between the cost of various components of concrete pavements and the effect of these components on increasing pavement life. ***(Goal 6)***	2 (Pending)	IPRF Task 6 (5/'02) IPRF Task 13 (Pending)	IPRF/APTech: "Task 6-Costs and Benefits of Various Components of Concrete Pavements" (5/'02) IPRF/ERES.: "Task 13- Determine Actual Life Cycle Costs" (Pending)	
c. Develop more accurate performance prediction models that can be used for making more timely rehabilitation decisions and for the development of performance related specifications. ***(Goal 6)***	1 (2002)		FHWA/ERES: "Project 14 - Validation of Performance Models for PCC Pave. Construction" (5/'99) NCHRP 1-37A/ERES: "Development of the 2002 Guide for the Design of New and Rehab. Pavement Structure" (12/'01)	
d. Identify and characterize relationships between the cost of various rehabilitation and maintenance alternatives and their effect on increasing the life of the pavement. ***(Goal 6)***	2 (2007)	Research Need 19.b IPRF Task 6 (5/'02) NCHRP 10-50A (11/'00)	IPRF/APTech: "Task 6-Costs and Benefits of Various Components of Concrete Pavements" (5/'02) FHWA/Texas A&M: "Repair and Rehabilitation Guidelines for PCC Pavements" (11/'02) NCHRP 10-50/Nichols Consulting Engineers: "Strategies for Rehab. Rigid Pave. Subjected to High-Traffic Volumes" (5/'99) NCHRP 10-50A/Texax A&M: "Guidelines for Selecting Strategies for Rehab. Rigid Pave. Subjected to High-Traffic Volumes" (11/'00)	
e. Determine the appropriateness of using discount rates for public projects since all allocated money will be spent. ***(Goal 6)***	2 (2005)			

APPENDIX C
Table of Research Needs Categorized by Level of Priority

Table 2. Prioritizing Research Needs

(12-10-00)

Color Code

IPRF or FHWA identified a similar research need.

Research needs taken from IPRFF Action Plan.

Research funded by either FHWA or IPRF relating to the research need identified.

Research recently funded by agencies other than FHWA or IPRF relating to the research need identified.

Research Need (Associated Goal) **Each research need is cross-referenced with table 1 using the identification label established in table 1.**	**Preliminary Research Required**	**Level of Priority (1, 2 or 3)**	**Year Funded**
LEVEL 1 PRIORITY			
5.b Provide guidelines for determining the w/c required to improve the performance of an aggregate source based on the durability of the aggregate. ***(Goal 1)***		1	2001
5.c Define the lower envelope of w/c's that can be used without excessive micro-cracking or self-desiccation occurring when considering the climatic conditions during paving and the curing techniques utilized. ***(Goal 1)***		1	2001
6.f Define adjustments required to take a mix design from the lab to the field. This would include quantifying the effects of mix times for various types of plants and plant conditions. ***(Goal 1)***		1	2001
8.c Evaluate and, if necessary, revise dowel diameter, length and spacing design procedures and guidelines to address not only bearing stresses but also curling/warping stresses and construction curling/warping built into the pavement. ***(Goal 1)***		1	2001
9.b Develop a design method for longitudinal reinforcement that incorporates not only tension due to friction or interlock between the slab and foundation but also bending fatigue resulting from a portion of the load being transferred by the reinforcing steel across cracks and diurnal curling. ***(Goal 1)***		1	2001
9.c Develop methods for controlling CRCP crack spacing. ***(Goal 1)***		1	2001
13.b Develop or investigate alternatives to current fatigue damage models for assessing concrete fatigue life. ***(Goal 1)***		1	2001
13.d Incorporate top-down cracking, as well as bottom-up cracking, into design procedures. ***(Goal 1)***		1	2001
16.a Develop a repeatable test for determining bond strength between pavement layers. ***(Goal 3)***		1	2001
18.b Quantify the variability that occurs in construction and in construction materials between projects and within projects and the effect the construction variability has on performance variability. ***(Goal 5)***		1	2001
1.a Identify the effects of the chemical composition and fineness of cements on the mixture and improve classification of cements. ***(Goal 1)***	NCHRP 18-5/Penn. State Univ.: "Relation of Portland Cement Characteristics to Concrete Durability" (7/'00)	1	2002

2.b Evaluate and compare the cost, benefits and risks associated with the use of pozzolans, GGBFS and ternary mixtures. ***(Goal 4)***		1	2002
2.d Characterize the interactions between pozzzolans, GGBFS and cementitious materials and develop rapid, field applicable test to demonstrate compatibility. ***(Goal 4)***		1	2002
4.i Identify procedures that can be taken to protect existing aggregate sources from urban development and to access sources that are currently difficult to retrieve because of environmental concerns and/or the presence of existing urban development. ***(Goal 1)***		1	2002
6.a Re-evaluate test criteria to determine whether they need to be revised to insure that concrete will perform well for 50 years. Develop alternative test criteria, if necessary. For example, pore structure criteria that are associated with good freeze-thaw durability for a 30-year design life may not assure adequate durability over a 50 year period. Tests used to assess the concrete materials and the concrete must be performance-related. ***(Goal 1)***		1	2002
6.b Identify the parameters required, including air void system requirements, for good freeze-thaw durability in higher strength concrete, which is typically associated with high early strength mixtures used for the reconstruction of high volume urban pavements. ***(Goal 1)***	FHWA/FHWA: "Project 3 - Freeze-Thaw Resistance of Concrete with Marginal Entrained Air Content" (12/'00)	1	2002
6.e Develop modified or improved methods of rapid and reliable testing and assessing the damage of freeze-thaw test specimens, building upon findings from a previous SHRP (C203) study. ***(Goal 1)***	FHWA/FHWA: "Project 3 - Freeze-Thaw Resistance of Concrete with Marginal Entrained Air Content" (12/'00)	1	2002
6.n Develop a method for characterizing the aggregate packing behavior in a concrete mixture based on the aggregate shape and gradation. ***(Goal 1)***		1	2002
8.b Identify the most suitable corrosion resistant materials for manufacturing dowel bars and/or dowel bar coatings. Evaluate the effects of these materials on the pavement system, e.g. possible ASR problems with fiberglass dowels, effects of coating thickness and material stiffness of bar on dowel looseness, etc. ***(Goal 1)***		1	2002
15.b Identify the early and long-term effects of curling and warping on concrete pavements. ***(Goal 1)***	FHWA/Univ. of Washington: "Project 20 - Identify the Early and Long-Term Effects of Curling and Warping on Jointed concrete pavements." (9/'00)	1	2002
17.c Develop improved equipment and techniques for performing PCC pavement repairs to reduce the time required per repair and improve repair reliability and performance. ***(Goal 3)***		1	2002
19.c Develop more accurate performance prediction models that can be used for making more timely rehabilitation decisions and for the development of performance related specifications. ***(Goal 6)***		1	2002
2.e Develop a test to be used for classifying mineral admixtures according to their ability to reduce or increase the ASR potential of a mix. ***(Goal 4)***		1	2003

6.o Quantify the effects of concrete production techniques and construction used in the field, such as shortened mix times, long hauls as a result of plant location, excess vibration, etc., on the durability of concrete. ***(Goal 1)***		1	2003
11.d Define the desired rate of drainage required for a pavement based on the structural design, the construction materials used and the environmental conditions. ***(Goal 1)***		1	2003
17.h More accurately predict the expected life for full- and partial-depth repairs, dowel retrofits and resealed joints based on the pre-existing condition of the repair area and the construction techniques used. ***(Goal 3)***	NCHRP 20-50(3/4)/ K. Hall: "LTPP –Effectiveness of Maintenance and Rehabilitation Options" (7/'01)	1	2003
18.a Quantify typical differences between designed and as-built pavement structures and identify the effects of these differences on pavement performance variability. ***(Goal 5)***	NCHRP 20-50 (05)/Consulpav International: "LTPP-Long-Term Variations in Pavement Design Inputs" (7/'01)	1	2003
18.e Quantify the influence of production and construction techniques on the difference between designed and as-built pavement structures. ***(Goal 5)***		1	2003
2.c Develop guidelines for the curing requirements of pavements constructed using concrete mixtures with pozzolans, GGBFS or ternary blends to ensure that adequate strength and durability are developed before placing the system in service or exposure conditions. ***(Goal 4)***	FHWA/FHWA & W.E.S.: "Project 14 - Performance of PCC Curing Materials and Procedures" (8/'01)	1	2004
6.i Develop guidelines for selecting curing materials and procedures suitable for various mixes and climatic conditions at the time of paving. ***(Goal 1)***	FHWA/FHWA & W.E.S.: "Project 14 - Performance of PCC Curing Materials and Procedures" (8/'01)	1	2004
13.c Calibrate 3-D finite models so that all input parameters, such as interlayer friction bonding and partial bonding can be incorporated into the design and evaluation procedures based on lab or field measurements. ***(Goal 1)***	Research Need 16.a	1	2004
16.b. 1. Determine the degree of bonding/debonding required for unbonded overlays or whitetoppings so that a sufficient amount of friction/bond is present to insure that working cracks form at the contraction joints, but so that not enough friction/bond develops to promote the reflection of distresses upward from the existing pavement. Identify surfaces and surface treatments that can meet these requirements. ***(Goal 3)*** 2. Determine the degree of bonding/debonding required for bonded overlays and thin/ultra-thin overlays to insure a monolithic behavior throughout the life of the overlay. Identify surfaces and surface treatments that can meet these requirements. ***(Goal 3)***	Research Need 16.a	1	2004
18.c Quantify long-term and short-term (daily and seasonal) variability for design input parameters and relate this to performance variability. ***(Goal 5)***	NCHRP 20-50 (07/12)/Univ. of Tennessee: "LTPP-Daily and Seasonal Variations in Insitu Material Properties" (1/'02) NCHRP 20-50 (05)/Consulpav International: "LTPP-Long-Term Variations in Pavement Design Inputs" (7/'01)	1	2004

3.a Characterize interactions between admixtures and cementitious materials and develop rapid, field applicable test to demonstrate compatibility. ***(Goal 1)***	IPRF/CTL: "Task 4- Tests or Standards to Identify Compatible Combinations of Individually Acceptable Concrete Materials" (4/'03)	1	2005
5.a Develop a systematic approach to determine the optimum w/c and permeability for each project based on the relationship between cost, constructability and durability. ***(Goal 1)***	Research Need 5.b Research Need 5.c	1	2005
8.d Establish design criterion for allowable bearing stress between the concrete and dowel. ***(Goal 1)***	Research Need 8.c	1	2005
13.a Identify the source or sources responsible for discrepancies between measured and predicted strains. If necessary, develop new models that more accurately predict pavement response to applied loads and environmental conditions. ***(Goal 1)***	Research Need 13.c Research Need 16.a	1	2005
4.h Develop a procedure that uses test methods that characterize the quality and durability of an aggregate to identify pavement and mix design components needed to optimize the performance of the pavement. ***(Goal 1)***	NCHRP 4-20/Texas A&M, 4-20A/Richard Meininger, 4-20B & 4-20C/Pending: "Aggregate Tests That Relate to Performance of PCC Pavements" (Pending)	1	Pending
6.d Determine the cause of the durability-related premature deterioration problems currently being encountered. ***(Goal 1)***	NCHRP 18-9/CTL: "Guidelines for Reducing the Premature Deterioration of Hydraulic Cement Concrete Pavements" (3/'01)	1	2001
8.a Determine the conditions under which concrete pavement joints should be sealed or could be designed as an unsealed joint. ***(Goal 1)***	IPRF/Pending: "Task 9 - Influence of Sealing Transverse Contraction Joints on the Overall Performance of Concrete Pavements" (Pending)	1	Pending
16.d Update currently available finite element pavement analysis programs to include the ability to model various degrees of bonding or friction between interlayers. ***(Goal 3)***	IPRF/ERES: "Task 10- Revision of ISlab 2000 for Subbase/Pavement Interaction" (12/'01)	1	2001
LEVEL 2 PRIORITY			
2.a Identify the effects of the chemical composition and fineness of mineral admixtures and improve classification of materials. ***(Goal 4)***		2	2003
4.b Develop guidelines for detecting, evaluating and treating material-related distress in concrete pavements. ***(Goal 4)***	FHWA/FHWA & Univ. of New Hampshire: "Project 22 - Residual ASR in Existing PCC, and Potential for Recycling and Repair" (8/'00) FHWA/Mich. Tech. Univ.: "Project 21 - Detection, Analysis And Treatment of Materials Related Distress in PCC Pavements" (10/'99)	2	2003
6.m Develop a test procedure or revise currently available procedures capable of rapidly determining the ASR potential of *concrete mixtures*. ***(Goal 1)***	FHWA/FHWA: "Project 2 - Development of a Mix-Specific ASR Test Method" (12/'00) ICAR/David Fowler: "Project 301 - Alkali-Silica Reaction in Portland Cement Concrete" (1/'01)	2	2003
9.a Identify reinforcing materials and treatments (steel coatings or treatments, new materials, e.g. polymeric materials) that can perform without corrosion throughout the design life of a long-life pavement. ***(Goal 2)***		2	2003
11.c Quantify how water flow in both stabilized and unstabilized bases change over the life of the pavement, especially for pavements with an extended design life. Develop analytical models that characterize these changes. ***(Goal 2)***		2	2003

14.b Develop a rigid pavement performance prediction procedure that can account for changing truck suspensions, tire types, axle configurations, legal load limits and permitted overloads. ***(Goal 1 & 2)***	NCHRP 1-37A/ERES: "Development of the 2002 Guide for the Design of New and Rehab. Pavement Structure" (12/'01) MnDOT/Univ. Minnesota: "Development of Vehicle Load Damage Factors for Rigid Pave." (9/'00)	2	2003
14.c Develop techniques for better modeling traffic flow during rehabilitation and reconstruction. ***(Goal 3)***		2	2003
15.a Determine whether construction materials meeting current specifications are sufficiently durable and corrosion resistant and will perform adequately when increasing the duration of their exposure to deicing chemicals as a result of increasing the life of the pavement by 20 years. ***(Goal 2)***		2	2003
16.e Develop a method for modeling reflective cracking using fracture mechanics and crack propagation models and incorporate the method into overlay design procedures. ***(Goal 3)***		2	2003
1.b Develop a method for determining the permissible alkali content based on the type of aggregate and the mixture that will be used. ***(Goal 1)***		2	2004
4.c Develop new techniques for obtaining good performance from lower quality aggregates that may be available locally for use in PCC. ***(Goal 1)***		2	2004
4.g Determine applicability of standard tests and acceptance criteria when applied to using recycled concrete as aggregate and PCC comprised of recycled concrete as aggregate. ***(Goal 4)***	FHWA/Univ. of Minnesota: "Project 5 - Physical and Mechanical Properties of Recycled PCC Aggregate Concrete" (5/'00)	2	2004
6.c Determine the effects of higher strength (which is typically associated with the high early mixes used for the reconstruction of high volume urban pavements) and associated concrete properties on pavement performance. ***(Goal 2 & 3)***	FHWA/Univ. of Mich.: "Project 19 - The Effects of Higher Strength and Associated Concrete Properties on Pavement Performance" (5/'00)	2	2004
11.a.1 Evaluate current pavement drainage system designs and materials to determine whether a 50-year performance life can be obtained. ***(Goal 2)*** 2. Identify drainage maintenance program needs for a 50-year design life and determine if these needs could/would be met. ***(Goal 2)***	NCHRP 1-34C/K. Hall: "Effects of Subsurface Drainage on Asphalt and PCC Pavements" (4/'01)	2	2004
17.e Develop repair guidelines for pcc concrete overlays. ***(Goal 3)***	IPRF/CTL: "Develop Repair Guidelines for Ultra-Thin and Thin Whitetopping" ('00) IPRF & FHWA/FHWA: " Task 5-Accelerated Loading Tests for Ultra-Thin Whitetopping" ('00)	2	2004
5.d Develop a quick, reliable test procedure to determine the water-cement ratio immediately before concrete placement. ***(Goal 1)***		2	2005
6.h Develop a cost-effective procedure for determining the air content of plastic concrete after placement. ***(Goal 1)***		2	2005
10.b Develop guidelines for choosing an appropriate type of base with respect to on-site conditions for each specific project. ***(Goal 1)***		2	2005
11.b Replace the saturated flow models currently used when designing pavement drainage systems with models that more accurately characterize water flow through the pavement structure and through the drainage system. ***(Goal 1)***		2	2005

12.a Determine the impact of texturing and surface treatments on tire/pavement interaction relative to safety, noise and comfort for both wet and dry conditions. ***(Goal 1)***	IPRF/?: "Task 2.-Impact of Surface Texturing on Reducing Wet-Weather Accidents." (3/'04)	2	2005
16.g Develop models that can predict the degradation of the bond between two paving layers over time and incorporate these models into pavement structural models and overlay design procedures. ***(Goal 3)***	Research Need 16.a	2	2005
17.f Develop a knowledge-based computer program to assist engineers in selecting optimal repair or rehab alternatives and appropriate materials and techniques for performing the work. ***(Goal 3)***	FHWA/Pending: "Project 24 – Repair and Rehabilitation Materials and Techniques for PCC Pavements" (1/'03) NCHRP 1-38/K. Hall: "Guide on Pave. Rehab. Strategies" (9/'00) NCHRP 10-50A/Texax A&M: "Guidelines for Selecting Strategies for Rehab. Rigid Pave. Subjected to High-Traffic Volumes" (11/'00) NCHRP 20-50(3/4)/ K. Hall: "LTPP –Effectiveness of Maintenance and Rehabilitation Options" (7/'01) Research Need 17.h	2	2005
19.e Determine the appropriateness of using discount rates for public projects since all allocated money will be spent. ***(Goal 6)***		2	2005
4.e Develop methods for providing better quality control for the production of recycled concrete as aggregate. ***(Goal 4)***		2	2006
4.f Identify the effects of using recycled concrete as aggregate on the design, construction and performance of concrete pavements. ***(Goal 4)***	FHWA/Univ. of Minnesota: "Project 5 - Physical and Mechanical Properties of Recycled PCC Aggregate Concrete" (5/'00)	2	2006
12.c Quantify the effects of aging on surface texture for various aggregate types, gradations and shapes and concrete mixtures. ***(Goal 1)***		2	2006
16.c Characterize the performance and develop a design procedure for whitetopping overlays on heavily loaded pavements. ***(Goal 3)***	IPRF/Transtec: "Task 3-Performance and Design of Whitetopping on Heavily Trafficed Roadways" (3/'04) FHWA & Mn/DOT/Mn/DOT: "Calibrating Design Procedures for Thin- and Ultra-Thin Whitetopping Using Measured Field Strains and Finite Element Modeling" (12/'01) IPRF & FHWA/FHWA: " Task 5-Accelerated Loading Tests for Ultra-Thin Whitetopping" ('00)	2	2006
17.a Develop new techniques and equipment that accelerate construction without sacrificing strength, durability, pavement smoothness and other measures of quality. ***(Goal 2)***		2	2006
17.b Develop construction- staging techniques that streamline and facilitate the reconstruction/rehabilitation/maintenance process by promoting the rehabilitation of long pavement segments as oppose to work performed in small clusters of unfocused effort. ***(Goal 3)***		2	2006
18.d Quantify the relationship between the cost of construction versus the qualtity of construction. ***(Goal 5)***		2	2006
13.f Develop or extend existing crack prediction models (such as HYPERPAVE) to include early age behavior of CRCP and long-term performance of JPCP. ***(Goal 1)***	FHWA/Transtec: "Project 16.-"Computer-Based Guidelines for Concrete Pavements" (1/'03)	2	2007

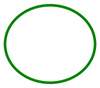
14.d Develop better traffic management strategies to decrease traffic congestion during reconstruction, rehabilitation and maintenance. ***(Goal 3)***	Research Need 14.c	2	2007
19.d Identify and characterize relationships between the cost of various rehabilitation and maintenance alternatives and their effect on increasing the life of the pavement. ***(Goal 6)***	IPRF/ApTech: "Task 6-Costs and Benefits of Various Components of Concrete Pavements" (5/'02) NCHRP 10-50A/Texax A&M: "Guidelines for Selecting Strategies for Rehab. Rigid Pave. Subjected to High-Traffic Volumes" (11/'00) Research Need 19.b	2	2007
16.f Develop improved guidelines and procedures for the design and construction of unbonded overlays. ***(Goal 3)***	IPRF/Pending.: "Task 8- Performance and Design of Separtated (Unbounded) Concrete Overlays" (Pending) Research Need 16.a Research Need 16.b	2	Pending
19.b Identify and characterize relationships between the cost of various components of concrete pavements and the effect of these components on increasing pavement life. ***(Goal 6)***	IPRF/ApTech: "Task 6-Costs and Benefits of Various Components of Concrete Pavements" (5/'02) IPRF/Pending.: "Task 13- Determine Actual Life Cycle Costs" (Pending)	2	Pending
LEVEL 3 PRIORITY			
4.a Develop a procedure for identifying the most cost-effective aggregate source for a construction project based on the cost of the material, which includes consideration of haul distances, the quality of the material, needed mix design adjustments, and projected long-term PCC performance. ***(Goal 1)***		3	2006
6.j Develop accelerated testing methods for more accurately predicting the long-term durability and performance potential of concrete so that mix changes made in the field do not detrimentally affect the performance of the pavement. ***(Goal 3)***		3	2006
6.l Identify and develop guidelines for the use of *durable*, fast-setting alternative materials that can be used in place of grout or concrete for partial depth repairs, full depth repairs and dowel retrofits. ***(Goal 3)***		3	2006
10.a Identify base materials that can provide an extended life without eroding, thaw weakening, heaving, decreasing in stiffness, or raveling and re-evaluate the applicability of current test criteria for a 50 year design life. ***(Goal 2)***		3	2006
13.e Develop a model that characterizes water flow through concrete so the stochastic moisture state can be considered while designing the pavement structure and the concrete mix if the regional climatic conditions are known. ***(Goal 1)***		3	2006
6.k Identify concrete, mortar and grout materials and mixes that have rapid strength development, are economical and are suitable for paving and pavement repair operations. ***(Goal 3)***		3	2007
12.b Develop equipment and a procedure for measuring pavement smoothness directly behind the paving machine. ***(Goal 1)***		3	2007
14.a Develop algorithms for predicting fatigue life based on load spectra, rather than ESAL's, using data from the LTPP database and/or results from accelerated load testing. ***(Goal 1)***	NCHRP 1-37A/ERES: "Development of the 2002 Guide for the Design of New and Rehabilitation Pavements Structure" (12/'01)	3	2007

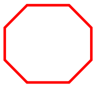
17.d Investigate the long-term cost-effectiveness of alternatives to milling out the old pavement under bridges when performing overlays (e.g., ultra-thin whitetopping, bridge jacking or replacing old bridges that have a remaining design-life of less than 10 years). ***(Goal 3)***		3	2007
17.g Identify methods to expedite the pavement break-up and removal process. ***(Goal 3 & 4)***		3	2007
19.a Improve the formalized processes available for quantifying delay times and vehicle operator costs (including fuel consumption) for project-level analyses so that they are implementable. The resulting user costs can then be incorporated into pavement management decisions based on life-cycle cost analyses. ***(Goal 6)***		3	2007
4.d Develop test that can identify durable aggregates before the quarry wall is mined. ***(Goal 1)***		3	2008
7.a Develop innovative pavement designs and construction techniques, such as two-course construction, that optimize the cost and performance of the pavement. ***(Goal 1)***		3	2008
6.g Develop a mechanistic approach for designing concrete mixes. Desired fresh concrete properties and hardened concrete properties will be the design objectives, which would be selected based on the pavement design, the construction techniques to be utilized and both the construction and long-term environmental conditions. The output should include types and quantities of materials, the order in which the materials should be combined and required mix times. ***(Goal 1)***	NIST/NIST: "Development of a Computer-Integrated Knowledge System (HYPERCON)" (2002) Research Need 2.d Research Need 4.a Research Need 4.h Research Need 5.a Research Need 5.b Research Need 5.c	3	2010

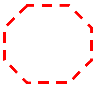
APPENDIX D

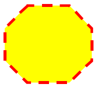
Flow Chart

FLOW CHART LEGEND


Research needs that are not dependent on the completion of other research needs or research projects that have already been funded or are pending.


Research needs that should not be funded until the research project (or projects) referenced below the research need has been completed and it is determined additional research still needs to be performed and the tools necessary to perform the research are available.

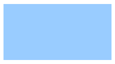

Research needs that might be met by on-going research projects. The results of these projects should be evaluated after they are completed to determine if the research need has been met.


Research needs that might be met by pending research projects. The results of these projects should be evaluated after they are completed to determine if the research need has been met.


Lines connect research needs when the completion of one need is dependent on the successful completion of another need (or needs).


Dashed lines connect research needs when the funding for a research need may not be necessary depending on the outcome of another research need (or needs).


Research needs that must be fulfilled to obtain Goal


Research needs that must be fulfilled to obtain Goal 2.

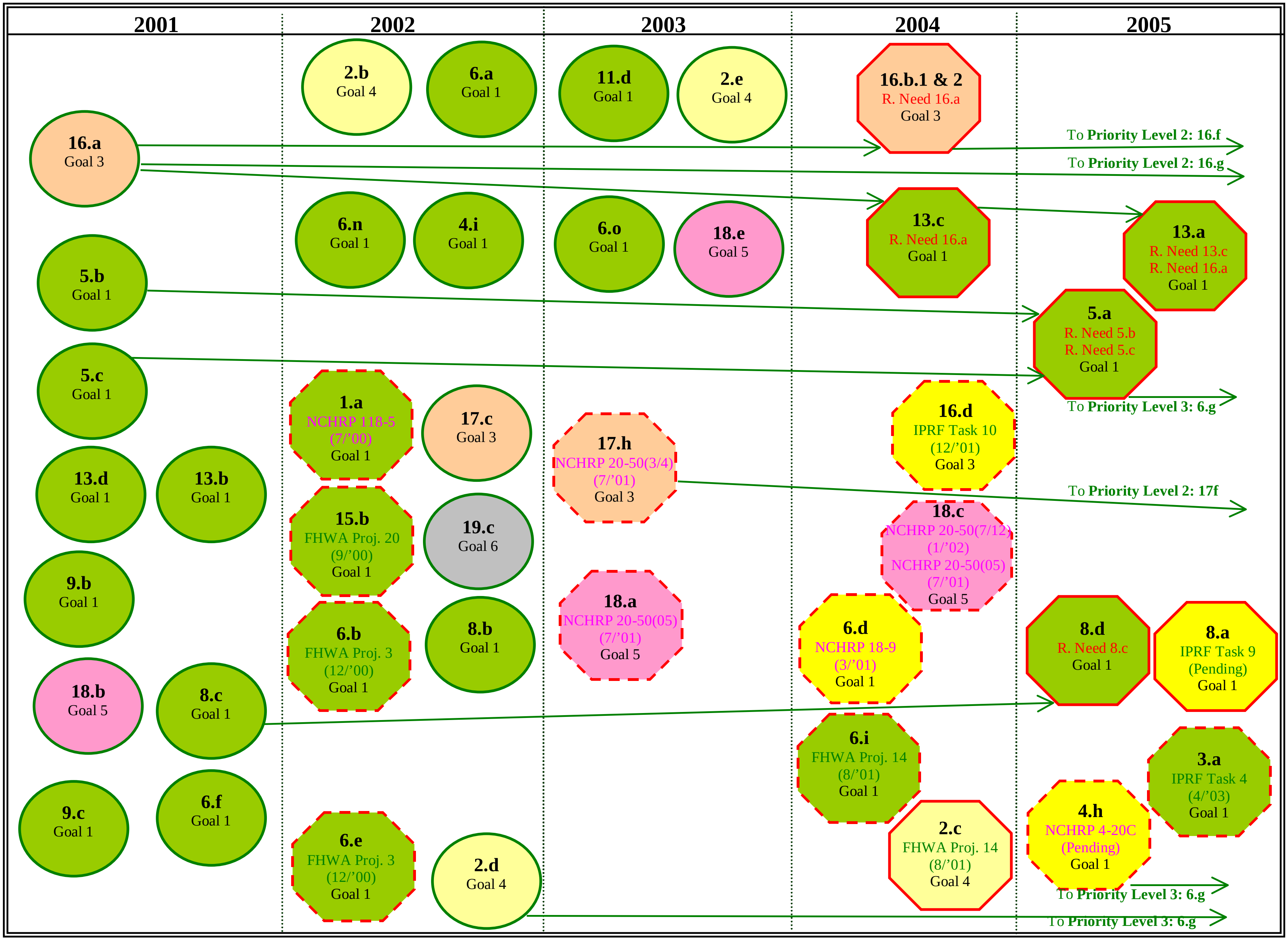
Research needs that must be fulfilled to obtain Goal 3.

Research needs that must be fulfilled to obtain Goal 4.

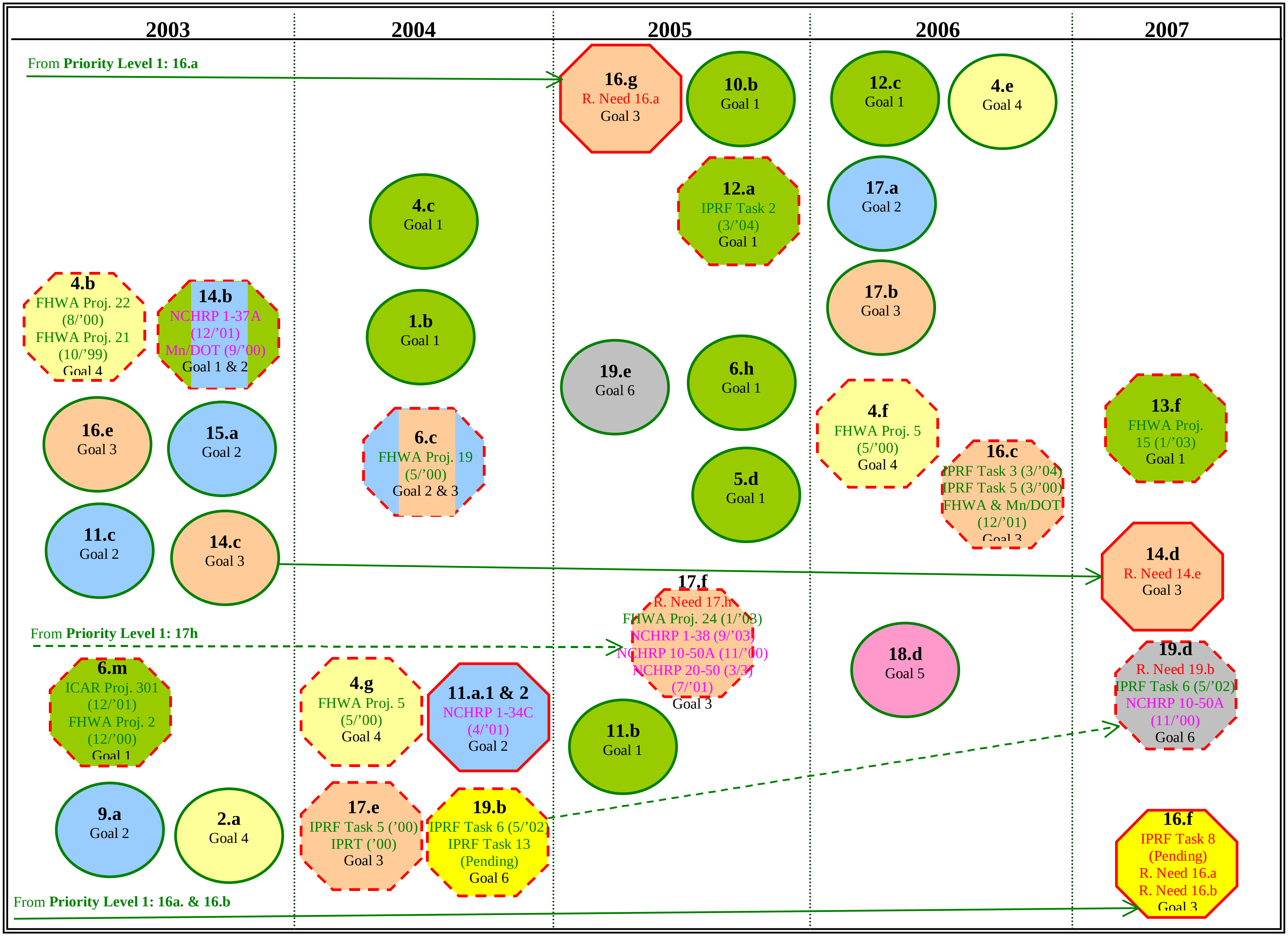

Research needs that must be fulfilled to obtain Goal 5.


Research needs that must be fulfilled to obtain Goal 6.

FLOW CHART: **Priority Level 1** (12-10-'00)



FLOW CHART: **Priority Level 2** (12-10-'00)



FLOW CHART: **Priority Level 3** (12-10-'00)