EXHIBIT A
SCOPE OF SERVICES

COMPOSITE PAVEMENTS

BACKGROUND
Composite pavements are pavement systems constructed with both portland cement concrete (PCC) and hot mix asphalt (HMA) pavement layers. Two types of composite pavements have been used in the past: HMA overlays of new or structurally sound existing PCC pavements (thermally insulated concrete pavements) and whitetoppings.

Thermally insulated concrete pavements (TICPs) consist of a concrete pavement structure (jointed or continuously reinforced) covered by an asphalt layer during construction (before opening to traffic) or soon after construction to address ride quality or surface characteristic issues. TICPs combine the structural longevity of PCC pavements with the serviceability of HMA pavements. One of the perceived benefits of TICPs is the simplification of the PCC design and construction through a thinner PCC layer due to reduced stresses in the concrete from the insulating effects of the asphalt layer, simplified finishing and simplified joint formation techniques.

There is a need for life cycle cost evaluation of TICPS and effective design and construction guidelines for applications where it has economic advantages. These guidelines should be based on a better understanding of the effects of design, materials and construction parameters on the performance of the TICPs. The research proposed in this pooled fund study aims to perform the life cycle cost comparison with alternative strategies and develop the required guidelines for mechanistic design and construction.

The study will focus on the initial questions of life cycle analysis, the environmental/climatic effects on performance, pavement design (interaction of concrete and asphalt thicknesses), materials properties for the asphalt and concrete materials and design details such as joint spacing, dowels and joint support. This investigation will determine an initial set of pavement structures that provide the best performance with respect to performance, constructability and cost-efficiency. The investigation will use a review of the literature, extensive mechanistic analysis combined with measured field properties and available information from field and accelerated pavement testing performance to determine the optimized set of pavement structures. These structures will then be available for construction and determination of more detailed extensive field and accelerated pavement testing performance data as validation of the design process. Thin asphalt overlays of PCC pavements encompass many of the same ideas as TICPs and they will also be considered in this pooled fund study.

The other type of composite pavement, concrete over asphalt, is often referred to as “whitetopping”. Since behavior and design of this type of pavement will be the subject of another pooled fund study initiated by the Minnesota Department of Transportation, the scope of this study will include PCC over HMA composite pavements in the literature review only.

OBJECTIVE
The main objective of the proposed research is to perform life cycle cost analysis comparisons and develop design and construction guidelines for TICPs (i.e. composite thin HMA overlays of new or structurally sound existing PCC pavements). The study also has the following secondary objectives:

1. Validation of the structural and climatic models of the Mechanistic-Empirical Pavement Design Guide (MEPDG) for asphalt overlays of concrete pavements.
2. Investigation of applicability of the MEPDG for design of TICPs.
3. Investigation of applicability of reflection cracking and asphalt rutting models developed in California.
4. Development of recommendations for feasibility analysis of newly constructed TICPs or thin overlays of the existing concrete pavements.

These objectives will be accomplished by collecting field performance data and evaluating the influence of design, material properties and construction on the performance of TICPs.

SCOPE

The research proposed in this pooled fund study aims to develop effective design and construction guidelines for TICPs. The study will focus on the initial questions of life cycle analysis, the effects performance of climate region, pavement design (interaction of concrete and asphalt thicknesses), materials properties for the asphalt and concrete materials and design details such as joint spacing, dowels and joint support. This investigation will determine an initial set of pavement structures that provide the best performance with respect to performance, constructability and cost-efficiency. The investigation will use a review of the literature, extensive mechanistic analysis combined with measured field properties and available information from field and accelerated pavement testing performance to determine the optimized set of pavement structures. These structures will then be available for construction and determination of more detailed extensive field and accelerated pavement testing performance data as validation of the design process. Thin asphalt overlays of PCC pavements encompass many of the same ideas as TICPs and they will also be considered in this pooled fund study.

Mn/DOT ASSISTANCE

Mn/DOT will construct and instrument the test sections, collect the pavement performance and pavement response data and upload the measured data into the MnROAD database.

WORK PLAN

Task 1: Development of Information on Composite Pavements

The project team will assess the state of practice and knowledge for the design and construction of composite pavement systems. The literature review will include projects and studies within the United States and foreign countries.

Placement of an AC overlay of an old deteriorated PCC pavement has been common practice by highway agencies for many years. These "composite rehabilitation" pavements have experienced mixed performance results, mainly due to the extensive damage existing in the old PCC pavements. Typically, reflection cracking has caused the early failures of AC overlays of JPCP due to joint opening and closing and to poor load transfer at the joints or at cracks. There have been many efforts to prevent and/or delay reflection cracking in these pavements but most have been ineffective.

The performance of AC overlays of CRCP has been much better as experienced in several states such as Illinois, Texas and Oregon, because if all punch-outs or ruptured steel cracks are repaired properly, very few reflection cracks have occurred over time if the overlays are two-inch or more in thickness.

Although the construction of new composite pavements is relatively rare, over the past 35 years there exists a useful body of knowledge and experience for design and construction of composite pavements. Many agencies have built composite pavements. Those agencies that envisioned composite pavements as a viable design strategy recognized the benefits of using AC as the insulating material and PCC as the load carrying material in areas with heavy trucks and problem soils to increase the service life and minimize maintenance. Composite pavements built in the 1960s and beyond have been shown to provide excellent service with minimal maintenance for 20 to 30+ years. Since the early 1980s, however, there has been little research in the area of new composite pavements.

In recent years, there has been resurgence in the construction of AC/PCC composite pavements in European countries. This includes Holland, Austria, Germany, France, Italy and the United Kingdom. Considerable AC/Roller Compacted Concrete (RCC) has been built in Spain and other countries. These composite pavements include a relatively thin AC layer (two-inch) over relatively thin CRCP (e.g., eight-inch).

The review of the state of practice will focus on two main issues: summarizing design and construction guidelines and identifying test sections or field projects to determine performance histories. It will include the design and construction of AC overlays of old PCC pavements and new composite pavement systems.

The team will start with a review of the procedures that have been used to design composite pavement systems. Items that will be summarized include design criteria, methodology of procedure, basis of procedure, distress prediction models, etc. The design/analysis procedures for composite pavements will be reviewed to determine those that are believed to have application and those that are considered inappropriate for use on further subtask activities.

The other focus of the literature review will be to develop a database of pavement sections to be used for validation/verification of the design guidelines developed in this study. For example, information on the following pavement sections will be collected:

1. Washington: Several true composite pavement projects were built in the 1960's and 1970's. Typical design included 4-in AC over 6-in JPCP without dowels.
2. California: Caltrans has placed asphalt overlays on relatively undamaged concrete pavements over the years. Some of these include thin rubberized overlays on JPCP.
3. Arizona: The Arizona Department of Transportation has extensive use of new or relatively new concrete pavements with thin high binder content asphalt rubber overlays. These have been used on most of the freeways in the Phoenix area.
4. LTPP sections, Global Positioning System (GPS)-2: There are several composite pavements in the GPS-2 experiment that consist of AC surfacing and a lean concrete base course.
5. Minnesota: Minnesota Interstate 394 AC overlay of a structurally sound PCC pavement
6. Tennessee: low volume composite pavements
7. Europe: Several countries including the Netherlands, Italy, United Kingdom, France and Belgium have built quite a number of composite pavements. Most of these composites include relatively thin (two to three inch) porous AC over CRCP. The thin AC layer is intended to reduce noise, splash and spray, provide good friction resistance and increase smoothness. It does not exhibit reflection cracks and waterproofs cracks in CRCP. Its limitations include a significant decline in the noise-reducing effect over time as the layer fills with materials, a relatively short life and higher deicing salt requirements to prevent icing.

Although the main focus of this study will be new composite pavements, the literature review will cover asphalt overlays of old concrete pavements as well. Based on the literature review, the research team will identify where the design and construction guidelines can be improved.

Deliverable(s): A Task Report, summarizing the literature review for new composite pavements and asphalt overlays of old concrete pavements

Duration: 12 Months

Task 2: Perform Initial Life-Cycle Analysis

In this task, a life cycle analysis will be performed, taking into account agency and user costs as well as environmental and sustainability aspects. This analysis will compare several hypothetical TICPs and overlays with conventional asphalt and concrete pavements to determine economically viable solutions and relative environmental costs.

The research team will collect the most recent information on construction cost of individual design features (AC layer, PCC layer, various types of the base layer, dowels, shoulder, widened lane, drainage, joint sawcutting, etc.) for California, Washington and Minnesota conditions. After that, a Life-Cycle Analysis will be performed to determine under what conditions use of composite pavement may be viable. This life cycle analysis will include a life cycle cost analysis and a Pavement Life Cycle Assessment Tool for Environmental and Economic Effects (PaLATE). These conditions may include the following cases:

- Longer pavement life of composite pavements compared to the pavement life of new PCC and AC pavements
- Lower construction cost of new pavement and potential lower maintenance costs
- Different materials resulting in different emissions, leachates and energy consumptions

The results of this task will be a thorough understanding and documentation of the absolute and relative costs of designing and constructing TICPs versus conventional pavements. LCCA for this task will consider agency costs only.

Deliverable(s): A Letter Report, containing a detailed description of the analysis and a summary of the economically viable design solution and corresponding required design lives

Duration: 9 Months

Task 3: Enhanced Integrated Climatic Model (EICM) Validation and Analysis

Although the construction of new composite pavements is relative rare, over the past 35 years there exists a useful body of knowledge and experience for both AC/PCC and PCC/PCC materials, designs and construction. The MEPDG also provides useful prediction models, analysis methodologies and a design procedure that, with further improvements and calibrations, can be made to provide reasonable prediction capabilities for “new” composite pavements. In this task, the researchers will investigate applicability of the MEPDG models for predicting structural responses of composite pavements.

As it was observed by Darter in Illinois based on survival analysis over many years, an AC overlay of CRCP typically carries twice the traffic (ESALs) of the original CRCP until it needs to be rehabilitated again. The reason why a relatively thin AC overlay could result in such a significant impact on load carrying capacity has been pondered for several years but has generally been attributed to the reduction in thermal gradients through the slab. The development of the new MEPDG has led to some quantification regarding the reduction of thermal gradients through the slab when a relatively thin overlay is placed. The EICM incorporated into the MEPDG is capable of predicting the temperature distribution throughout the pavement thickness. The EICM has been extensively validated for conventional flexible and rigid pavements. Very limited validation has been done for the structures similar to TICPs.

In this task, the research team will conduct extensive validation of the EICM. An extensive sensitivity analysis will be conducted to ensure that the predicted temperature distributions are reasonable for a wide range of the input parameters that might be expected for composite pavements. The following parameters will be considered:

- AC and PCC layer thicknesses
- AC and PCC thermal conductivities and heat capacity
- Properties of the base layer and subgrade
- Geographic location of the pavement section

The temperature distributions predicted with the EICM will be carefully evaluated. Results that do not make sense will be flagged and an attempt to resolve the problems will be made by adjusting the EICM internal parameters. If for certain combinations of the input parameters the research team is not be able to correct the problems, those combinations will be flagged and the research team will contact the Applied Research Associates (ARA) for assistance.

After that, the comparison of the predicted and measured temperature distributions will be made. Several slabs of the exiting PCC pavement section were overlaid with a two-inch thick AC layer. Thermocouple sensors are retrofitted into the PCC slab prior to overlay and installed into the AC layer during the construction. A comparison of the temperature gradients in the PCC slab will be performed.

This will be followed by an extensive analytical investigation of the effect of various TICPs designs on the reduction of PCC slab curling and joint movements due to presence of the HMA layer. Critical design, material and construction features will be identified. In addition to the parameters identified above, the following parameters are expected to have the most effect:

- The coefficient of thermal expansion of the PCC layer
- PCC joint spacing
- PCC slab width

Deliverable(s): A Letter Report, summarizing validation of the EICM model and analytical investigation of the effect of various TICPs designs on the reduction of PCC slab curling and joint movements

Duration: 10 Months

Task 4: Evaluation of Pavement Response Models
In this task, the research team will use the information collected at the MnROAD test sections to evaluate and adapt available computer models capable of predicting pavement response to load and environmental effects. The responses of the MEPDG structural model, ISLAB2000, will be compared with the measured responses from the test sections. The following data will be analyzed:

- FWD test results
- Joint opening
- Strains

In addition to the analysis of the responses from the composite pavement section, the responses from the adjacent pavement sections will be compared with the correspondent responses of the composite sections.

Deliverable(s): A Letter Report; PowerPoint Presentation

Duration: 12 Months

Task 5: Develop Design Guidelines
In this task, the research team will develop guidelines for the design of composite pavements. The main focus of this task will be adaptation of the MEPDG procedure for the JPCP cracking model and supplementing it by the CalME procedure for AC rutting. To develop these guidelines, sensitivity analyses will be performed using performance models described below.

The MEPDG composite pavement design and analysis was developed specifically for AC overlays and PCC bonded overlays. Thus, while having this comprehensive model available is extremely advantageous, there are some significant limitations that must be evaluated and deficiencies addressed. The following performance prediction models will be evaluated:

- PCC fatigue cracking (top/down and bottom/up) of AC overlays of PCC pavements
- Transverse joint faulting

Since the focus of the SHRP 2 project R21 will be focused on evaluation and adaptation of the MEPDG AC models for composite pavements, this study will be focused on evaluation and adaptation for design of composite pavements of the following CalME models:

- AC reflective cracking
- AC rutting

MEPDG Cracking Model
It is anticipated that the information obtained in Tasks 4 and 5 will enable the research team to validate and adopt the PCC cracking model for design of AC/PCC pavements.

A comprehensive sensitivity analysis using the MEPDG software will be conducted to evaluate the effect of various design features on the predicted cracking of the PCC layer. The following design parameters will be considered:

- AC layer thickness
- AC mix properties
- PCC layer thickness
- PCC layer properties (strength, modulus of elasticity and coefficient of thermal expansion)
- PCC joint spacing
- PCC slab width

The most attention will be paid to the combination of the design features identified in Task 2 as economically feasible to check if those combinations can provide acceptable performance.

MEPDG Faulting Model

Although the MEPDG does not predict joint faulting for AC/PCC pavements, the JPCP faulting model can be adopted for design of composite pavements was well. A comprehensive sensitivity analysis using the MEPDG software will be conducted to evaluate the effect of various design features on the predicted faulting of the PCC layer. The following design parameters will be considered:

- AC layer thickness
- AC mix properties
- Dowel diameter
- PCC joint spacing
- PCC layer thickness
- PCC layer properties (strength, modulus of elasticity and coefficient of thermal expansion)

Reflection Cracking Model

Reflection cracking is a fracture in an AC surface layer above any joints and cracks in the supporting PCC layer and is the predominant distress that has been exhibited in composite pavements. The MEPDG incorporates an empirical placeholder for prediction of this distress. In this study, alternative procedures for the reflection cracking prediction will be considered. These approaches will be based on several major reflection cracking studies of AC/AC and AC/PCC composite pavements conducted by UCPRC. Those studies included accelerated pavement testing with the Heavy Vehicle Simulator (HVS) and development of performance prediction models.

Two different reflection cracking models have been developed by the UCPRC that consider most of these variables: a) a fatigue approach, and b) a continuum damage mechanics (CDM) approach.

In the fatigue approach, which has been coded into software called CalME (working with Per Ullidtz of Dynatest Inc. as subcontractor) reflection cracking damage is calculated by a two step process. First, the tensile strain at the bottom of the overlay is estimated using a regression equation based upon extensive finite element studies. This equation considers the following variables: stiffness and thickness of the overlay materials, slab length (or distance between cracks), stiffness of the underlying slabs, stiffness of the support layers beneath the slab.

Second, the calculated tensile strain at the bottom of the overlay is used in a fatigue equation calibrated to the field performance of the AC materials under consideration to calculate damage in the asphalt layers.

Finally, damage has been correlated with percent of wheelpath cracked in the field for AC on AC overlays; for TICPs a similar transfer function will need to be developed for percent of joints with reflection cracking. The CalME software performs this analysis using recursive updating of the damage with each hour of traffic applied from the axle load spectrum to the pavement. The current version of CalME includes the ability to perform the analysis using fatigue characterization of the asphalt overlay using a two-stage Weibull equation that considers both crack initiation and propagation, rather than repetitions to 50 percent loss of stiffness as is traditionally used. This procedure has also been calibrated using HVS tests on both jointed PCC and cracked asphalt concrete, for conventional, polymer modified and rubberized mixes, including thick and thin overlays.

Rutting Model

Rutting is a potential problem for asphalt overlays of concrete pavements. The MEPDG rutting model relates rutting in the asphalt layer to the elastic modulus of the asphalt overlay. It was not calibrated for overlays placed on concrete pavements. In this study, an alternative procedure for the asphalt rutting prediction will be considered. These approaches will be based on several major rutting studies of AC/AC and AC/PCC composite pavements conducted by UCPRC. Those studies included accelerated pavement testing with the Heavy Vehicle Simulator (HVS) and development of performance prediction models. The model has also been calibrated using accelerated pavement testing data from the Westrack project.

In this approach, the inelastic deformation of the pavement is calculated based on traffic load repetitions and calculated elastic shear strain and shear stress using layer elastic theory. The calibration factor relating the inelastic deformation to the elastic responses is characterized in the laboratory using the repeated simple shear test. The field rut depth is related to the calculated inelastic shear strain using a calibration factor developed from the HVS and test track calibration studies. Those calibrations are currently being validated using NCAT test track and MnROAD data and laboratory tests being performed on materials from those projects. A number of mixes have already been characterized by this approach including conventional dense graded asphalt, rubberized asphalt gap-graded mixes, dense graded polymer modified mixes and terminal blend gap-graded mixes.

This approach includes a method for calculating rutting in overlays in which different materials are used to make up the overlay, such as a polymer-modified wearing course on a conventional asphalt leveling course. While this approach needs further refinement, it offers significant advantages over the approach currently included in the MEPDG because of its ability to handle modified binder mixes and consider different materials in the overlay.

Deliverable(s): A Letter Report, documenting adaptation of the MEPDG procedure for the JPCP cracking model and supplementing it by the CalME procedure for AC rutting

Duration: 16 Months

Task 6: Develop Construction Guidelines

Once the general ideals of composite pavement design have been solidified, a group of experts in materials and construction will be convened to determine constructability of composite pavements. This panel will evaluate materials, methods, sequencing and value engineering (the idea that certain items normally associated with PCC or HMA pavements can be modified for composite pavements to save time or money; for instance, PCC surface smoothness is not needed to the degree that it is in a PCC pavement). The following issues will be addressed:

- Profile control (ride is achieved with the HMA layers)
- Required cure time before the HMA can be placed
- Joint forming versus sawing
- Roller compacted techniques
- CRCP techniques
- Construction sequence

The use of CA4PRS pavement construction schedule estimating software for TICPs alternatives will be investigated. The software will be used to develop estimated construction schedules for construction of alternative structures. Recommendations for any updates to the software to handle this type of construction will be developed based on the experience of this part of the investigation.

Deliverable(s): A Letter Report, documenting development of the construction guidelines

Duration: 13 Months

Task 7: Develop Synthesis

The research team will prepare a synthesis.

Deliverable(s): Synthesis of Practices

Duration: 7 Months

Task 8: Draft final report

The research team will prepare a final report that contains the following:

- A summary of experience to date based on the literature survey.
- A description of the MnROAD test sections.
- A detailed description of the data that has been collected, where the data is stored and how it can be accessed.
- A detailed description of the environment, structural and performance model and their predictive capabilities.
- A summary of the pavement designs considered, the expected performance based on the sensitivity analyses, expected construction schedule and approximate life cycle cost over a common analysis period. This will provide a recommendation for the best structures for the different conditions (environment, traffic, costs in different locations) considered in the analyses.
- Recommendations for best practice for each of the conditions considered in the sensitivity analysis factorial.
- Identification of issues that need further research and development to further improve this technology.
- Information addressing relevant issues to advise the participating state departments of transportation on possible changes in the design and construction specification to accelerate the implementation of the results of this study.

Deliverable(s): Draft Final Report

Duration: 7 Months

Task 9: Prepare Final Report
The research team will address the panel comments on the final report.

Deliverable(s): Final Written Report

Duration: 4 Months

PROJECT SCHEDULE

MONTHS

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Task 1	X	X	X	X	X	X	X	X	X	X	X	X					
Task 2				X	X	X	X	X	X	X	X	X					
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Task 5												X	X	X	X	X	X
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	18	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**
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Task 4	X	X	X	X	X	X	X										
Task 5	X	X	X	X	X	X	X	X	X	X							
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Task 8							X	X	X	X	X	X	X				
Task 9														X	X	X	X

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