**Development of Hot-Mix Asphalt Layer Thickness Design for Longer-Life Asphalt Pavements**

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## *ABSTRACT*

Flexible pavements with thin bitumen surfacing form one of the largest infrastructure components in the Australian sealed road network and are a complex system of multiple sub-layers of different materials and combinations of variables. More effective and rational pavement analysis and design which can incorporate the performance characteristics and failure mechanisms of pavements relating to realistic conditions are needed to overcome current design shortcomings. This research project will initiate a new pavement design methodology, providing a more realistic approach for pavement design. It will bring about an advance in pavement design and analysis, and result in more effective analysis and design of pavements world-wide.

## *AIMS AND BACKGROUND*

Flexible pavements with thin bitumen surfacing form one of the largest infrastructure components in Australia with around 300,000 km of sealed road network (AUSTROADS, 2004; Main Roads Western Australia, 2009), and are a complex system of multiple sub-layers of different materials. They must also withstand combinations of variable, and in some cases seasonal, traffic loading, and varying environmental conditions. The surfacing of sealed road pavements may be either asphalt or sprayed seals. Asphalt surfacing is generally applied to pavements in urban environments, and is subject to traffic conditions ranging from extremely light in residential streets to extremely heavy in major arterial and industrial roads. The overall performance of flexible pavements with asphalt surfacing is related to the performance of both the supporting pavement structure and the asphalt surfacing, which interact in a complex manner to carry the applied loads. In sprayed seal pavements, some of which carry extremely heavy traffic, it is related solely to the performance of the supporting structure.

Realistic prediction of the long-term service life of flexible pavements is critical and challenging due to the increasing stress generated by increased axle loads and tyre pressures, as well as the ever-increasing volume of traffic. The current method of pavement analysis and design does not model the performance characteristics and failure mechanisms of the base and subbase layers within the pavement, and does not model fatigue failure of pavements with thin asphalt surfacing. The current method also precludes the use of asphalt layers between 60 and 120 mm in heavy-duty pavements citing premature fatigue failure, despite this thickness being proven sound in many pavement repairs. This research project will be the initiation of a new pavement design methodology that includes all pavement layers and uses the results of field trials and past pavement performance to test the model, providing a more realistic approach for pavement design which models all pavement layers, material characteristics and traffic loads.

The current design methodology also does not consider tangential forces generated by acceleration and braking forces applied to the pavement. With the increasing use of road trains and the increased tangential forces required to move the total load up grade and away from a standing start, it is becoming increasingly important to model these loads.

### *Project Objectives*

This project aims to achieve successful and reliable design methodology for pavements incorporating intermediate hot mix asphalt (HMA) layer thicknesses. This methodology will characterise all pavement layers in order to eliminate the unreliability of the current design method, which ignores the development of permanent strain, excessive elastic strain and shear failures of the base and subbase pavement layers, which may lead to excessive strain in the asphalt layers. In addition, the model will consider forces generated during acceleration, braking and the force needed to maintain movement of heavy vehicles generated by the drive wheels. The project will lead to improved analysis and design procedures of HMA layer thickness and structural pavement, which together with the research training offered through the conduct of this work, will result in cost-effective and highly reliable design and use of HMA. To achieve these aims, the research objectives are:

1. To identify any problems in the current HMA thickness design and pavement structural design to address their shortcomings,
2. To establish an effective analytical approach which can integrate most factors affecting actual pavement performance into pavement response prediction,
3. To define innovative pavement design criteria which encompass all failure modes tending to occur in every pavement layer, and
4. To establish a new design approach for HMA layer thickness to obtain rutting-resistant, durable, impermeable and fatigue-controlled characteristics of longer-life pavements with more than 30 years in service without major damage.

### *Background*

#### General

There is considerable industry debate about the assumptions and reliability of pavement design methodology and predictions of pavement material performance, both of which are vital inputs into the construction and maintenance of a reliable, but economical road network in Australia.

Hot Mixed Asphalt (HMA) is the most widely used road surfacing and resurfacing material in urban areas in Western Australia (and Australia). However there are serious concerns regarding the design for new and rehabilitated pavements incorporating both thin and deep strength asphalt layers, as well as stabilised pavement where the current Austroads method (AUSTROADS, 2004) of pavement design does not accurately reflect historical performance.

Generally, for Australian structural pavement design, most of the road and highway agencies and industry follow the current version of AUSTROADS Guide to Pavement Technology Series: Part 2 Pavement Structural Design (AUSTROADS, 2004). However, the Australian method of pavement design fails in three main areas for the design of pavements with granular layers and relatively thin asphalt surfaces. These three deficiencies are 1) no fatigue life prediction for a thin asphalt layer, 2) questionable performance prediction of asphalt layers in the 60 to 80 mm depth range, and 3) no consideration of permanent deformation in base/subbase layers. The current version of the AUSTROADS Pavement Structural Design Guide also has shortcomings in the design of full-depth asphalt pavements where the existence of a shift factor between laboratory predictions of fatigue life of asphalt and actual fatigue life of asphalt in the pavement was recognised. Furthermore, all of the factors involved in HMA layer thickness design and structural pavement design have been extrapolated far beyond the bounds of the original data and existing test protocols: current experience shows these require detailed re-investigation. Our work sets out to remedy all of these shortcomings.

### *Hot Mix Asphalt (HMA)*

After sprayed seals, the most common type of flexible pavement surfacing in Australia is Hot Mix Asphalt (HMA), and this type of surfacing is used in locations of both the highest stress in urban arterial roads, and lowest stress in urban residential streets. HMA is recognised by many different names such as hot mix, asphaltic concrete (AC), asphalt, and bitumen. The properties of HMA are distinguished by its application, which determines the ratio between an asphalt binder (bitumen), filler and aggregates to achieve the best performance of mixes, requiring a balance between stability, fatigue and oxidation life depending on traffic conditions. HMA is manufactured by heating the bituminous binder to decrease its viscosity, and heating and drying the aggregate prior to mixing. Mixing is generally performed with the aggregate at roughly more than 150 °C for a common asphalt type. Paving and compaction must be performed while the asphalt is sufficiently hot.

HMA is used as part of a pavement structure to distribute stresses caused by loading, and to protect the underlying unbound (or bound) layers from the effect of water. To sufficiently perform both of these functions over the pavement design life, HMA must also withstand the effects of air and water, resist permanent deformation, and resist cracking caused by loading and the environment. Many factors affect the ability of HMA to meet these structure requirements. Mix design, construction practices, properties of component materials, and the use of asphalt additives all play a major role in the resulting structural characteristics of a pavement. It is also important to recognise the interaction between HMA mix design and pavement structural design to arrive at the most cost-effective solutions (Epps, Harvey, Kim, & Roque, 2004).

Epps, Harvey, Kim, & Roque (2004) reported on the challenges and opportunities which road and highway agencies as well as the asphalt pavement community should address in the near future. These challenges include;

- Changes in the properties of component materials, primarily in the availability of modifiers and manufacturing processes that can be used to

assist in engineering the asphalt mixture, but also in the availability of good sources of the two main components, asphalt and aggregates,
- Increased severity of the conditions under which asphalt mixtures are expected to perform, primarily greater contact stresses, loads, and load repetitions, including changes resulting from advancements in tire technology,
- More restrictive constraints on the time frame and production requirements of pavement rehabilitation and reconstruction operations, especially in urban areas where traffic delay is an important issue, and
- Increased need to reduce the adverse environmental impacts of asphalt mixture production and paving, through to reuse of materials from existing pavements and other sources.

In this proposed project, the first three challenges of the above list are addressed.

*Pavement Analysis and Design*

Desai (2007) described various approaches for the design, maintenance and rehabilitation of pavements. That experience and knowledge of index properties such as the California Bearing Ratio (CBR) are the key input factors for the empirical approach, which limits in shear failure and in deflections (Huang, 1993). All indexes and empirical properties may exclude the effects of multi-dimensional geometry, loading, realistic material behaviour and spatial distribution of displacement, stresses, and strains in a multi-layer pavement system. Consequently, the use of empirical approaches can be evaluated only in a limited capacity (Desai & Whitenack, 2001).

The mechanistic–empirical (M–E) approach is based on limitations in mechanics principles such as elasticity, plasticity, and visco-elasticity. It consists of two stages: the first is an analysis of the pavement layer system using a mechanistic model such as the layered elastic concept and Finite Element (FE) procedure that includes elastic, non-linear elastic (*e.g.,* resilient modulus model), or elastoplastic models such as Von Mises, Mohr–Coulomb, and hardening or continuous yielding (Vermeer, 1982). In the second stage the stresses and strains from the wheel load, computed from the first stage, are usually used in empirical formulae to determine rutting, damage, cracking, and cycles to failure.

The full mechanistic (M) approach is only an idealised method at the current time. It would be able to address all factors in stage two of the M–E approach without the use of empirical formulae, in a unified manner for all layers. As a result, the distresses would be evaluated as a part of the solution (*e.g.,* finite element) procedure, without the need for empirical formulae (Desai, 2007).

In Australia, the current pavement design method relies on the AUSTROADS Pavement Design Guide (AUSTROADS, 2004). The guide has been promoted at the level of a mechanistic–empirical design method, where the performance of a pavement structure can be determined from the application of an analytical process together with empirical formulae. Current pavement design uses an analytical process to determine the response of the pavement structure to a single load and a critical response: either the horizontal tensile strain at the bottom of an asphalt layer or the vertical compressive strain at the top of the subgrade layer. The strain is used as an input parameter into empirical formulae as a performance relationship that relates the critical response to the allowable number of design axles/traffic.

The current AUSTROADS design method for thin asphalt surfaced and spray surfaced granular pavements does not allow for the potential for modelling failure of the granular layers of the pavements, nor does it adequately predict the fatigue life of thin asphalt surfaces. There are many examples and anecdotal evidence from practitioners that the current design methodology does not work well in heavy traffic, particularly in rehabilitation treatments of existing roads in heavy traffic, where extreme loads are exerted on the pavement as soon as it is opened to traffic. Asphalt surfaced granular pavements subject to heavy traffic designed in accordance with current AUSTROADS methods and using materials conforming to current specifications are requiring extensive treatment for fatigue failure in two to ten years.

The current AUSTROADS method also prevents asphalt thicknesses of between 60 and 120 mm indicating fatigue failure in very early life, but in practice, pavements milled and filled with asphalt layers in this thickness range have outlasted predictions of life by factors of five or more. It is recognised that for bituminous products, there is a shift factor of somewhere between 10 and 60 times laboratory predictions of field performance and actual field performance. This is due in part to the laboratory scale of the test beams, but also to the accelerated frequency of load applications, that do not mimic the rest periods in real traffic conditions. Many practitioners are concerned that the current design methods are producing excessively expensive and over-designed pavements, and preventing the adoption of longer-lasting cheaper alternatives that fall between a granular pavement and a fully bound pavement.

## *Modelling of HMA in pavements*

Kim (2009) reported how an asphalt model is critically important to current pavement design and analysis. Various factors affect the deformation behaviour and performance of an asphalt surface including time (*i.e.,* rate of loading, loading time, and rest period), temperature, stress state, mode of loading, aging, and moisture. Models have been developed to capture the effects of these factors on the asphalt surface performance. Most of the past and current models are inherently empirical. The reason for the empirical nature of these models is the lack of computing power necessary to calculate the long-term performance of asphalt pavements. In recent years in the USA, the Strategic Highway Research Program (SHRP) recognised the importance of mechanistic models for material specifications, mixture design, and pavement design, and developed a range of research products based on the principles of mechanics. The paradigm shift from empiricism to mechanics during the SHRP made a significant impact on the role of models in asphalt pavement engineering (R. Kim, Y., 2009).

Development of a more fundamental performance model serves two important purposes as: 1) for pavement engineers, such a model can provide accurate information about the performance of asphalt pavements under realistic loading condition, leading to a better assessment of the service life of a new pavement and of the remaining life of an existing pavement, and 2) for material engineers, a performance model founded on basic principles of mechanics provides relationships between material properties (chemical or mechanical) and model parameters, which can be used for the selection or design of better-performing binders or mixtures (NCHRP 1-37 Research Team, 2004).

*HMA Performance Characteristics*

HMA performance can be categorised into two major types of distress: cracking and permanent deformation. Cracking on HMA can be caused by mechanical loading from repetitive traffic, and/or thermal loading from changes in temperature. When HMA is subjected to repeated loading, whether mechanical or thermal, distributed microstructure damage occurs primarily in the form of microcracks. Propagation, coalescence, and rebonding of these microcracks affects macrocrack growth and healing, and thus the fatigue behaviour of HMA. For these characteristics, the modelling of fatigue behaviour of HMA requires an evaluation of the effects of both micro- and macrocracks and their interaction on the global behaviour of the HMA mixture (Park, Kim, & Schaper, 1996).

At high temperature and/or slow loading rates, the asphalt binder becomes too soft to carry the load, and thus the principle type of damage is permanent deformation due to the volume change and rearrangement of aggregate particles caused by shear flow. The degree of aggregate interlocking and anisotropy in HMA caused by aggregate orientation under compaction become relevant factors in the accurate prediction of permanent deformation characteristics of HMA in pavements (D. Kim & Kim, 2006).

*Pavement Response Model versus Performance Model*

A conventional approach to the prediction of asphalt pavement performance is divided into two steps: 1) pavement response prediction, and 2) pavement performance prediction. For pavement response prediction, responses of an undamaged pavement (*e.g.,* tensile strain at the bottom of the asphalt layer and compressive strains at the top of the subgrade layer) are estimated from a structural model (*e.g.,* the multilayered elastic theory) using initial, undamaged properties of the layer materials. For pavement response prediction, asphalt (HMA) performance models are developed using laboratory test results, and relate to the initial response of HMA specimens up until the life of those specimens. The responses estimated from the structural model are then input to the performance model to determine the life of the pavement. This approach is the state-of-the-practice method adopted in most recent mechanistic–empirical pavement design methods, including the AUSTROADS Pavement Design Guide (AUSTROADS, 2004).

These models are simple to use because the only measured response of the mixture is at the initial stage of fatigue testing. Such models deserve credit for the basic foundation of current mechanistic–empirical pavement design. However, there are several weaknesses in this traditional approach (Epps *et al.*, 2004). They are:

- Damage evolution in complex structures and modified materials may not be captured accurately. For example, complex combinations of layer material types and thicknesses in perpetual pavements make it more difficult to accurately predict failure mechanisms using conventional hot mix asphalt (HMA) performance prediction models and pavement response models.
- Most performance models used in the two-step approach are mode-of-loading dependent. These models are established using results obtained from laboratory tests, which are performed either in controlled stress modes or in controlled strain modes. Currently available two-step approaches do not have sufficient ability to distinguish the mode of loading mechanistically, and therefore could result in an unreliable performance prediction.

- The laboratory test methods used in the traditional two-step approach are designed to simulate the boundary conditions of pavement structures, rather than to define the material's constitutive behaviour in the representative volume element (RVE) (R. Kim, Y., 2009). Often these laboratory test methods predict performance under only some selected pavement conditions. Because the test methods simulate the pavement boundary conditions rather than capture the behaviour of the material's real condition, the number of tests needed to cover the wide range of pavement conditions expected in the field is undesirably large.

The shortcomings of the two-step approach can be overcome using a mechanistic approach combining HMA material models and the pavement response model. In this approach, the material model describes the stress–strain behaviour of the material as a real condition. The material model is then implemented into the pavement response model where boundary conditions for the pavement structure in question are applied. This approach provides an accurate evaluation of the effects of changes in layer stiffness due to damage growth on pavement performance. Prediction of multiple performance characteristics and their interactions is possible in a realistic manner, although material models in both tension and compression are needed.

The lack of computing power available to calculate damage evolution for the entire life of the pavement forced earlier researchers to develop the two-step approach to pavement performance prediction, as opposed to the more realistic one-step integrated approach.

However, improvements in computing power and numerical techniques now allow modellers to implement more powerful material models into the pavement response model, and to predict pavement performance directly from the integrated model.

## Longer-Life Pavement Design

Von Qunintus (2001) proposed a design procedure based on limiting the tensile strain at the bottom of the HMA layer and the vertical compressive strain at the top of the subgrade or embankment soil. Long life was defined in his work as +40 years without any major structural failure throughout the HMA layer. The design traffic used in design studies exceeded 40 million equivalent single-axle loads.

The methodology applied the cumulative damage concept in the prediction of fatigue (load-related cracking) and subgrade distortion. Seasonal and other variations in material properties, including the modulus of the HMA layer, were considered in the procedure by use of the "equivalent modulus" concept. In other words, the incremental damage computed in the HMA layer for a specific modulus was equal to the summation of the incremental damage computed, allowing the modulus of the HMA layer to change with the season. Two other criteria were used for mechanistic–empirical thickness design checks. One was based on limiting the maximum surface deflection under the design load, and the other was based on limiting the modulus ratio between two adjacent unbound pavement layers. With this methodology, three key issues related to fatigue cracking in HMA layers were addressed. The first issue was the reality of the concept of an *"endurance limit"* for the layer thickness design of HMA layers. The second issue was the location where load-related cracks initiate in the HMA layer (at the bottom of the layer versus the top of the layer), and the third issue was confirmation of the fatigue characteristics of HMA layers for use in layer thickness design. Some of the Long-Term Pavement Performance data (both materials and distress data) were used to support the criteria employed in the design procedure and methodology of that procedure (Von Qunintus, 2001).

## *SIGNIFICANCE AND INNOVATION*

### *Significance*

Of key significance in the proposed project is the generation of realistic guidelines for the analysis and design of HMA and granular layer thickness based on a more fundamental analytical approach and the full consideration of more realistic pavement conditions. The results of our work will then specifically yield:

- a more effective pavement analysis and design process based on a complete and comprehensive characterisation of all pavement layers,
- a design methodology that more accurately reflects actual pavement performance, including thicker layers of asphalt that are currently excluded by the design process but historically have proven performance, and
- a realistic shift factor for use in predicting actual asphalt fatigue life versus laboratory performance, thus making significant savings in asphalt cost and resource consumption, with the potential to layer asphalts with specific properties for each layer within a full depth asphalt pavement.

When the results are applied, they will:

- improve pavement analysis and design methods for WA,
- improve highway and road construction methods relating to HMA,
- increase the reliability of highway and road construction and rehabilitation in WA, and
- reduce consumption of valuable non-renewable resources.

The study is scientifically significant because it will be the most complete investigation of a new mechanistic design, based on sophisticated tests and scientific characterisation, and implementing mathematical models and finite element procedures. Furthermore, this proposed project is a university–industry collaboration, which is unique in this field and enhances hands-on research and education.

### *Innovation*

The proposed project is innovative because it:

- Has as its goal the development of analysis and design procedures for a longer-life pavement, based on an advanced overall concept of integrating all influencing factors in the procedures; this is in contrast to current analysis and design methods where uncertainty is engendered by the use of empirical methods that do not model all pavement layers and exclude significant applied loads,
- Brings together state-of-the-art numerical methods and innovative sophisticated laboratory testing to identify and develop the appropriate HMA constitutive and performance models,
- Brings the mechanistic concept to formalise mathematical and numerical models, computational models, and experimental results so as to accurately simulate pavement material behaviour in pavement during traffic loads, and

- Is based upon our ability to apply the pavement longer-life design concept (more than 30 years in pavement service life) to an overall pavement design approach – all other studies have been based partly upon conventional methods.

## *APPROACH*

### *Overview*

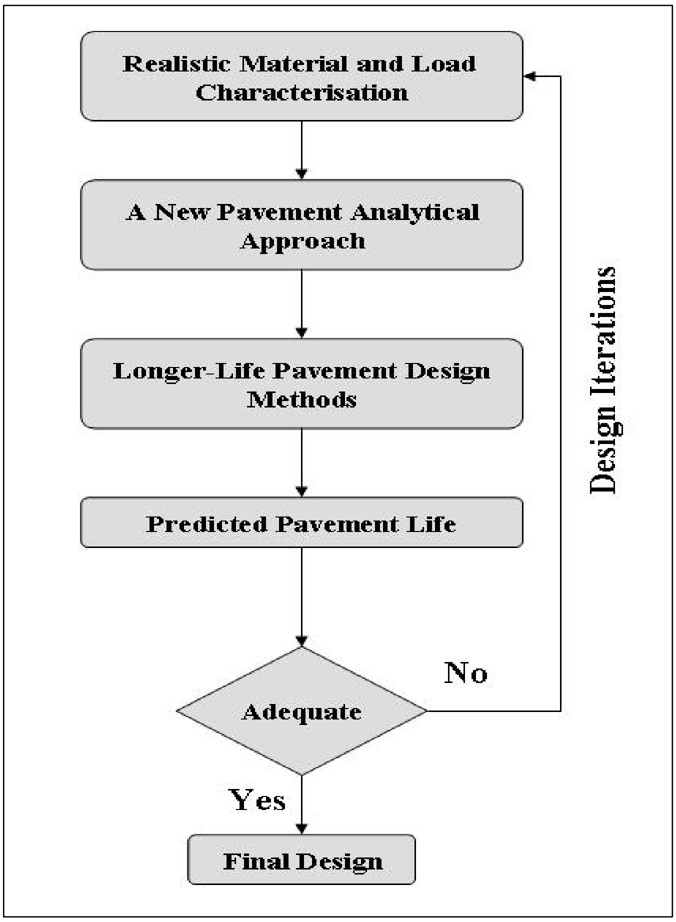


Figure 1 shows the overview concept of the approach of this study. The main concept of the longer-life pavement design proposed is that *"realistic inputs (loads, materials and pavement conditions) can be processed by a new analytical approach to obtain the precise pavement response in terms of stresses, σ, and strains, ε, which are used in the pavement design method to evaluate pavement performance which is used to judge the acceptability of the multi-layer system of the design pavement"*

The design starts with input of the load and material characterisation based on the realistic conditions of pavements, moving loads, seasonal effects, temperature, and the like. The pavement analytical approach will involve constitutive material models, the Finite Element Method (FEM), and model validation of the multilayer system, resulting in the pavement response to the loading condition expressed in terms of stresses (σ) and strains (ε) at critical positions in the pavement structure. The pavement response serves as input to the pavement criteria, as the transfer functions which will be established are based on more realistic and sophisticated tests for each material type, relating the stress–strain condition to the number of loads that can be sustained before a certain terminal condition is reached.

**Figure 1:** Proposed pavement design method

### *Approach and methodology details*

The proposed approach and methodology, consisting of three stages as shown in Figure 2, incorporates the following key activities that contribute to the fulfilment of the project objectives identified earlier. In this part, we provide detail of our proposed methods.

*Stage 1 (Objective 1)*

Stage 1 of this project will gather relevant information and identify the problems of current HMA thickness design and overall pavement design. A literature review of HMA and pavement design proposed by various researchers for different design methods will be performed to provide reliable inputs for the improvement of the current design methods used in Australia. The design methodology will be tested by comparisons with pavement distress that occurs in the early life of actual pavement in a study area, together with accurate recording of traffic information. The tasks in Stage 1 will: 1) identify the advantages and disadvantages of current design methods from different sources to determine the design factors, concepts and methods compatible with all conditions of a study area, 2) identify pavement distress patterns to determine the triggers of various pavement failure mechanisms, 3) relate items 1) and 2) to accurate traffic loads on identified trial pavements. Outcomes from this stage will identify all shortcomings of the current design approach and provide direction for stage 2.

*Stage 2 (Objectives 2&3)*

Stage 2 develops a new pavement analytical approach which is distinguished from the current approach by incorporating all applied loads and all pavement layers, rather than the simple assumptions of static loads and the assumption that base materials meeting simple index tests will not fail by shear or permanent strain accumulation and excludes fatigue failure of any asphalt layer less than 50 mm thick.. Innovative inputs which represent realistic conditions will be determined. For these inputs, moving loads causing changes in stress stages and loading times in pavements, dynamic material properties based on temperatures and amplitudes and frequencies of traffic loads, and realistic damage mechanisms of HMA fatigue and/or rutting of subgrade and base layers by permanent deformation will be evaluated to set up the numerical modelling inputs for pavement analysis. These innovative (more realistic) inputs will be used in a powerful finite element program (expected to be the ABAQUS program) in which appropriate constitutive material characteristics and loading pattern simulations will be performed. Numerical modelling of the whole pavement system will be undertaken to determine the pavement response, stresses ($\sigma$) and strains ($\varepsilon$) at critical positions in the pavement system and to investigate the behaviour of the whole pavement system under a typical load. A laboratory scale pavement system model will be constructed to validate this analytical approach. This physical model will be built by simulating the real pavement configuration as modelling in the finite element program. In this stage, the outcome will be a strong analytical approach for pavement design in the next stage.

*Stage 3 (Objectives 3&4)*

Stage 3 develops an innovative design process. The structural deterioration of flexible pavements is associated with fatigue cracking in the HMA surface, or development of ruts in the wheel path. This design will apply the cumulative damage concept in the prediction of these two modes of distress, while maintaining the concept of no distortion in the base/subbase layers where their appropriate depths will be determined. Using the cumulative damage concept permits accounting, in a rational manner, for damage caused by each load application. Seasonal and other variations in material properties and modulus of each layer with different loads can be considered in these predictions of damage. Evaluations of design life for candidate pavement structures are based on computing the damage caused by realistic loads (from Stages 1&2) for different seasons of the year, and summing the results to obtain the total damage to the pavement structure.

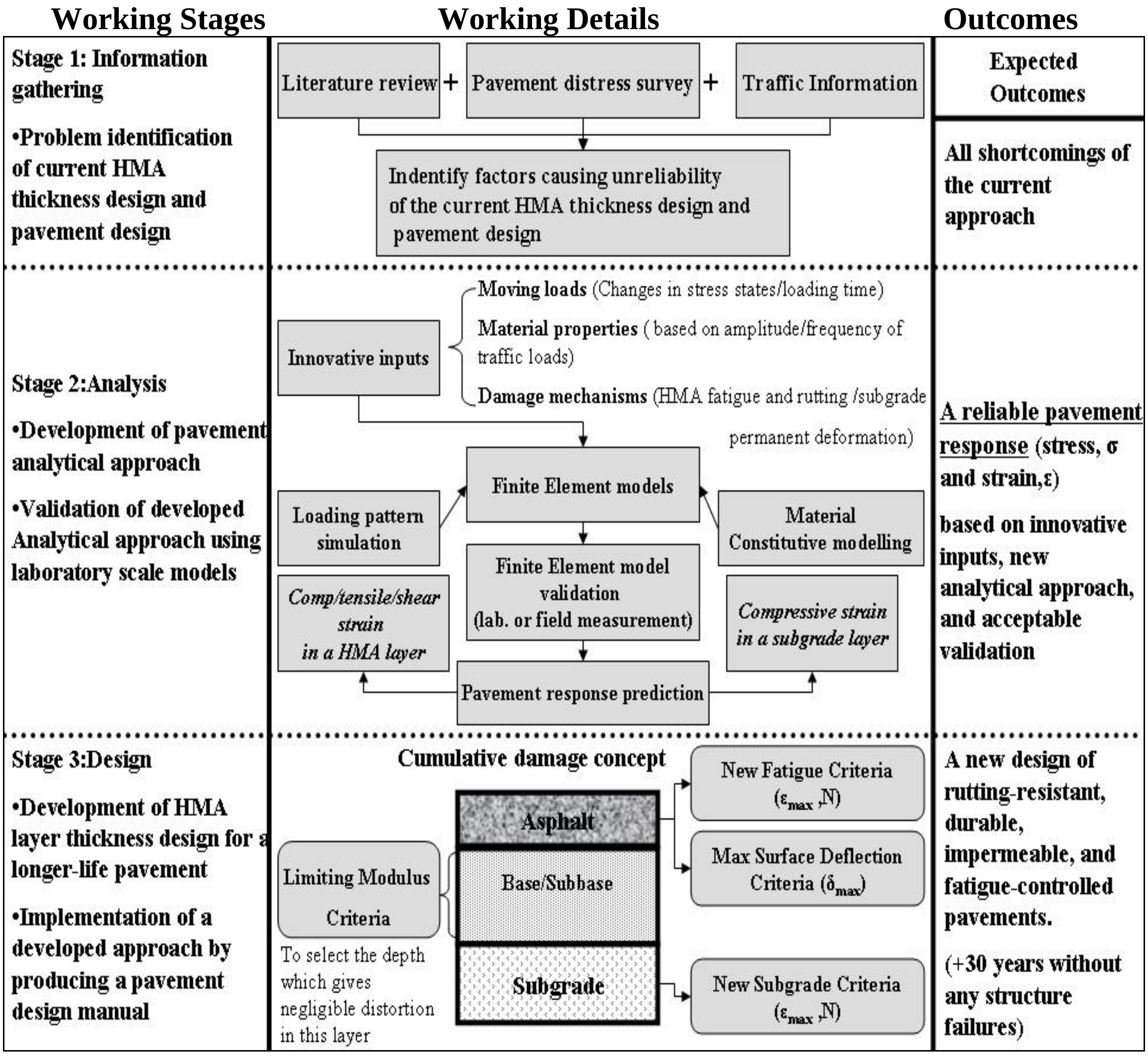


**Figure 2:** Approach and methodology details of the proposed project

The main purpose of the design effort is to provide pavement structures that will serve the design traffic levels projected through a design period before experiencing failure. Failure of flexible pavements will defined as a specified fatigue cracking area or a specified depth of rutting in wheel path areas, which would be compared to the distress survey in Stage 1 and historical performance of HMA pavements. The failure of a pavement system under this concept will be assumed to occur when the damage index (the ratio between the existing fatigue and/or rutting and the specified failures) reaches a fixed amount, generally 1.0. It should be understood that a damage index of 1.0 does not necessarily imply a functional failure, but is instead the level of damage selected as sufficient to warrant maintenance or rehabilitation. For this study, the specified failures in terms of an area of alligator cracking and rut depth will be determined from studies of in-service pavements. These levels will usually trigger some type of pavement rehabilitation, for which the proposed methodology will be equally applicable.

Two other criteria will be used for the mechanistic–empirical thickness design checks. One is based on limiting the maximum surface deflection, and the other is based on limiting the modulus ratio between two adjacent unbound pavement layers. These two criteria and the rutting and fatigue criteria used for the design checks are discussed and defined in the following paragraphs.

*Structural Response Criteria*

- *Limiting Modulus Ratio Criteria for Unbound/Bound Aggregate Layers*

The long-term in-place modulus of unbound/base and subbase layers are dependent on the modulus of the supporting layer because of potential de-compaction in the lower portion of these layers. In this study, the Finite Element Program will be used to develop criteria to limit the modulus of unbound aggregate layers, based on the thickness of a base/subbase layer and the modulus of the layer supporting the base/subbase layer. The purpose of this criterion is to imply that the structural layer above the subgrade for foundation will be constructed such that only negligible distortion will occur within those layers.

- *Subgrade Deformation Criteria*

Rutting or surface distortion is considered to occur primarily in the subgrade, and is related to the vertical compressive strain at the top of the subgrade. In this study, the relationship between vertical compressive strain and number of wheel load applications for various subgrade stiffness values will be established from the laboratory and field test results with realistic conditions in a study area. These will be used to approximate a failure level of subgrade rutting or distortion.

- *Base and Subbase Deformation Criteria*

Rutting or surface distortion can potentially occur within the pavement structures and is related to the vertical compressive strain at the top of the individual layer. In this study, the relationship between vertical compressive strain and number of wheel load applications will be analysed for various material properties, and methods to predict this included in the design method.

- *Fatigue Cracking Criteria*

Fatigue or alligator cracking in flexible pavements results primarily from repeated wheel loads in situations where excessive elastic strain is evidenced. Fatigue cracking is not well understood, and it is currently debated whether fatigue cracking initiates from the bottom of the asphalt layer or the top. In reality, the initiation of fatigue cracking will likely be a function of asphalt thickness and base stiffness, and cracking may commence either immediately under wheel loads or adjacent to wheel loads. The proposed model will enable prediction of both failure mechanisms. In this study, new fatigue cracking criteria will be developed based on a clear picture of the crack mechanisms, laboratory test results, field investigation, and numerical modelling.

- *Maximum Surface Deflection Criteria*

The maximum surface deflection under a particular axle load has been used for pavement design and evaluation. The critical deflections will be used to judge the acceptability of the pavement design cross-section, and not to predict the occurrence of specific distress.

Finally, a design manual based on this proposed analysis and design will be developed to implement this concept of longer-life pavement and HMA thickness design.

### *Project plan*

The proposed project will span three years, based at Curtin University of Technology. Project sequences, timings, and activity locations are summarised in Table 1.

**Table 1:** Gantt Chart for Project (note that years are broken into three-month periods)

| **Activity** (Project objective numbers, see C2.1, in parentheses) | **Year 1** | | | | **Year 2** | | | | **Year 3** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Information gathering (1)** | | | | | | | | | | | | |
| Literature/Pavement distress survey/Traffic information | X | X | X | X | | | | | | | | |
| Identify current pavement design | | X | X | X | | | | | | | | |
| **Development of an analytical approach (2&3)** | | | | | | | | | | | | |
| Modelling pavement in finite element program | | | | | X | X | X | | | | | |
| Validation of an analytical approach (lab. scale pavement model) | | | | | | | X | X | X | | | |
| **Development of a design approach (3&4)** | | | | | | | | | | | | |
| Defining material failure criteria | | | | | | | | X | X | X | | |
| Applying the longer-life pavement concept | | | | | | | | | X | X | X | |
| **Development of the longer-life design manual (4)** | | | | | | | | | | X | X | X |
| Reports and papers | | | | | | | | | | | X | X |

## *NATIONAL BENEFIT*

Increasing demands on the road and highway network to support economic growth makes pavement construction a priority for Australia’s population. Effective and rational pavement analysis and design, with better fundamental understanding and more convincing analysis and design concepts than the current mechanistic–empirical design (with its design output being an approximated value), will contribute to enhancing the nation’s construction industry.

The proposed project addresses **National Research Priority 3: Frontier Technology for Building and Transforming Australian Industries** and **Associated Priority Goals of Breakthrough Science**.

The development of an advanced analytical approach for pavement design and analysis, and better understanding of longer-life pavement design processes in pavement engineering, will underpin greater longevity, reduced costs, and sustainability in the highway and road construction industry. The key outcomes of this study will benefit highway and road organisations, contractors, engineers and others interested in the analysis and design of pavements. This is particularly so in light of the recent change to a new era of analytical approaches, rather than the empirical approach of the past and current mechanistic–empirical design. Application of the outcomes of this project will improve overall road and highway quality. This will have a significant impact on Australia’s society and economic growth because of the relationships between the extent and quality of road infrastructure and national per capita income (Queiroz, Haas, & Cai, 1994).

***PARTNER ORGANISATION COMMITMENT AND COLLABORATION***

The City of Canning, City of Stirling, City of Swan, City of Perth, and the Australian Asphalt Pavement Association (AAPA) are strongly committed to the project, with financial commitments of AUD 5,000, 5,000, 5,000, 5,000, and 20,000 per year respectively, giving AUD 40,000 per year in total, together with significant in-kind support for this three-year project. The cash contribution requested from the ARC (around AUD 56,000 pa) represents 52.3 % of the total funds (as detailed in Part D) required.

This project will initiate closer cooperation and strategic research alliances between Curtin University and industry. Local Government and AAPA in Western Australia have had little involvement with Curtin or any other Universities in undertaking strategic research. This project will demonstrate both to the participating agencies and to the wider Local Government community the potential for closer relationships, where the combination of academic excellence and practical knowledge can meld together to bring wider benefits to both the University, industry and the wider community.

The contributions to this project include both cash and in kind contributions. The cash contributions are made specifically for the initiation and application of targeted research by the University into the design and performance of road pavements. The in kind contribution is in two ways; each organisation will contribute technical staff to guide the research to ensure that the outcomes are realistic and applicable to the future design of road pavements and, where specific trial pavements are required, partner organisations will construct these pavements supplying materials, equipment and labour. Where specialist testing is required that is not available within Curtin, the partner organisations will undertake this testing and pass the results to Curtin.

Where testing is undertaken by Curtin in the field, the partner organisations will supply traffic management and any labour and equipment required to complete the testing.

The successful completion of this project with associated design reliability and whole of life cost savings to the partner organisations and to the community as a whole will demonstrate to Local Government the benefits of closer collaboration with the academic community The benefits will be to both develop better understanding of applied theory to practice, in reduced whole of life costing inclusive of environmental and sustainability considerations, and the development of future talent for the industry in providing students and academics who are able to apply theory with a greater understanding of the relevance of their research. .

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