Mechanistic-Empirical Pavement Design — Where are we headed?

By David Newcomb, P.E., Ph.D.

This article is the sixth in a series on the subject of Mechanistic Pavement Design. Previous articles have presented an overview of the subject, a discussion on modeling, aspects of materials characterization, a discourse on traffic predictions, and the empirical relationships between pavement responses to load and performance. The new pavement design guide has been developed under a National Cooperative Highway Research Program project, and it is time to understand its potential impact on the industry. This article, along with the previous five, can be downloaded from www.hotmix.org/technology.php.

The National Cooperative Highway Research Program (NCHRP) has supported an effort to develop a mechanistic-empirical pavement design procedure for both flexible and rigid pavements through project 1-37A. Originally slated for completion in 2002, this project was to result in a design procedure that would consider the same inputs in terms of climate and traffic for the two pavement types, and then through a process of modeling would consider material properties and come up with distress predictions. Depending upon the designer's definition of an acceptable level of distress, he or she would then begin a process to define the properties and layer thickness that would produce that level of distress at the desired time in the pavement's life.

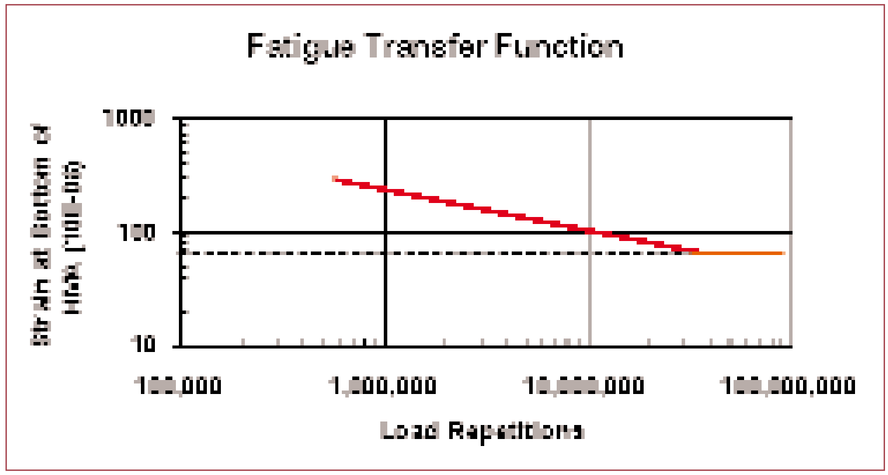
As stated in previous *HMAT* articles, there are many advantages to mechanistic-empirical pavement design procedures. It is possible through the analysis procedure to relate not only pavement thickness, but also material properties to performance. Because traffic is characterized in a more detailed manner, its effect on performance can be more accurately portrayed. If the reliability analysis is properly formulated, the effect of construction and materials variability on performance can be estimated. Finally, the pavement can be engineered specifically to address particular types of distresses.

Although NCHRP Project 1-37A is complete, much remains to be done on the road to implementing mechanistic-empirical pavement design procedures. Any new design method must have a demonstrated reasonableness in matching designs that have worked well. The input and output must contain data and results that are obtainable and sensible. It must reasonably predict the performance of pavements to a degree that can be verified. The procedure should allow an evaluation of the impact of input data on the reliability of the design. Perhaps most important, a new design procedure must be explainable to and understood by its users. This article will discuss the future in terms of research and implementation activities that are needed.

Demonstrated "reasonableness"

The existing empirical design methods have served well for many years to ensure that the structures we have in place would be adequate. As our understanding of the causes of distresses increased, the design methods evolved accordingly. For instance, when the AASHO Road Test was conducted in the late 1950's, the thickest section of HMA that was tested was 6 inches, and this reflected the practices of the time. It was also an attempt to obtain pavement distresses within the time frame of the AASHO Road Test, which only lasted two years. However, as it became clear that thicker sections of HMA were needed to preclude fatigue cracking in heavy traffic conditions, full-depth and deep-strength asphalt pavements began to emerge. Now, we have come to realize that there is an upper limit on the HMA thickness needed to avoid fatigue cracking, and the idea of Perpetual Pavements is gaining momentum.

In the end, it must be remembered that the design methods of the past were rational, just not mechanistic. Any new mechanistic method should match the experience of the past in terms of providing similar designs for similar materials, climate, and traffic conditions. This test of reasonableness would then give users confidence in trying new approaches to design through the use of innovative materials.



Transfer functions control the design of the pavement and they must reflect the current understanding we have. For instance, the endurance limit concept shown here is one of the features of a realistic transfer function.

Matching the precision of input to the accuracy of the output

The soils and materials that go into pavements have inherent variability in their properties. Thus, while controls are in place for the production and placement of materials, their properties change with time and location. For instance, soils change with geology and their behavior is largely dependent on the amount and type (frozen or unfrozen) water in them. Their consistency from point to point is dependent upon terrain, e.g., mountainous cut and fill versus a deep dry lakebed. Likewise, granular base materials and HMA properties will vary according to geographic regions and the time of year. Any material properties and their changes used in design need to reflect the gross changes in weather that occur with time and need to recognize the variability in material sources.

There have always been questions as to the accuracy of traffic predictions when designing new pavements. The ability to forecast volumes and vehicle distributions has been more miss than hit. Who could have foreseen an increase in truck traffic of 145 percent in terms of vehicle-miles in the past 30 years? Another 36 percent increase is envisioned by 2013 – How accurate will that estimate be? What changes might occur in truck loading in the future? Will greater gross vehicle weights be allowed? Will super-single tires finally emerge on the scene, even though the concern about them expressed 10 years ago never materialized? This could have an impact on the way HMA surface layers are designed in particular. But, nobody knows for sure what kind of traffic will appear on a given road network or highway.

It is important for designers to maintain a sense of reality when dealing with material and traffic inputs to mechanistic-empirical analysis. Since design is done well ahead of construction, the material properties will need to reflect those of typical materials used in similar conditions. Focusing on small changes in modulus values such as might occur on a daily or hourly basis will yield little in terms of an improved design and may result in extremely long computation time when one considers the design extending over 20 to 40 years. A monthly or seasonal approach would probably better serve in assessing a structural cross-section. Traffic should be characterized in terms of the present classification count with typical weight and tire considerations and the projected increase in volume.

Contain accurate performance estimates

The transfer functions or performance equations used to estimate the life of the pavement need to reflect what we know about pavement performance. In past mechanistic-empirical methods as well as the new proposed method, the transfer functions usually assumed a straight-line form on a log-log plot that either structural rutting or fatigue cracking would occur no matter how low the stress was in the pavement. Thanks to work at the Transport Research Laboratory in the

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United Kingdom, as well as efforts at the University of California Berkeley, University of Illinois, the Asphalt Institute, and the National Center for Asphalt Technology, our understanding of long-life pavements has evolved. Below a certain level of stress or strain, damage does not accumulate in the materials. This limiting strain or endurance limit needs to be included in our design procedures. For without this concept, increasing thickness of pavement will be needed for increasing strain, and this flies in the face of a body of experience with long lasting or Perpetual Pavements.

It is important that the transfer functions used in predicting specific types of distresses have substantial calibration and validation before being used in design. Such equations should also reflect local conditions in that what dictates pavement performance in Montana is very different from that which is important for Florida. If transfer functions differentiate between similarly appearing distresses such as top-down versus bottom-up cracking in the wheelpath, it is imperative that the research be undertaken to allow the accurate prediction of either type of distress. In other words, as the equations are developed, field observations must allow for the determination of the origin of the cracks.

The rate at which damage accumulates is another area that needs to be investigated. Most mechanistic-empirical design procedures use Miner's Hypothesis to model the accumulation of damage. This approach makes the simplifying assumption that damage accumulation is the same whether a given level of stress is applied at the beginning or end of the structure's life. In other words, the rate of damage accumulation is constant,

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even though in most cases, it is probably not. Fatigue damage most likely starts slowly and accelerates with time as the distress appears. Rutting, on the other hand, may start at the outset of hot weather and slow as the material consolidates or age hardens over time.

To some extent, this information should be available in pavement management systems databases. States have been required to maintain a pavement management system for a number of years now. Some, such as Washington State, have been tracking pavement performance since the early 70s. By correlating the occurrence of distresses to traffic levels, pavement design, and materials, transfer functions can be developed for use in mechanistic-empirical design. Such transfer functions need to be validated through careful study of selected sites by means of trench studies to discover the origins of the distresses and by testing materials in the roadway.

Allow analysis of reliability sensitivity

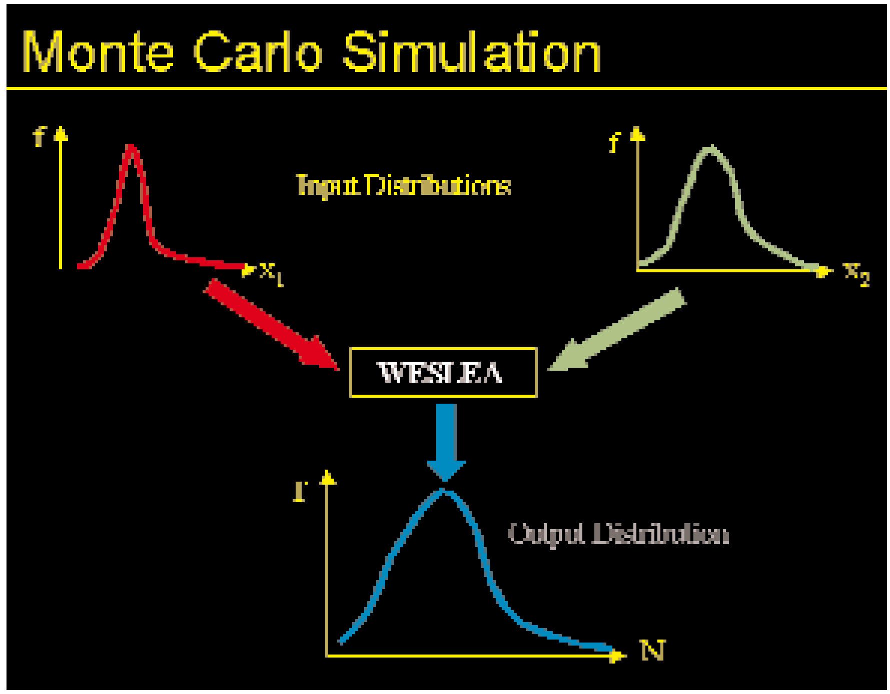
The 1993 AASHTO guide provided an introduction to the effects of reliability on the performance of pavements. Essentially, as the level of reliability increased, the performance improved. This meant that pavements with higher reliability had a greater thickness. In the 1993 guide, reliability can only be considered in the grossest terms since it only handled reliability on the general level of pavement performance and its variability.

Since that time, reliability has been introduced to mechanistic design by means of Monte Carlo or other types of simulation analyses. The variability of the input parameters is used to estimate the variability of the pavement's performance. That way one can tell the impact of improving product consistency through quality control or improving the subgrade strength to be more uniform. Reducing the variability of inputs through better control will improve the reliability of the pavement design and this should be reflected in the design process. It is one of the basic tenants of performance related specifications.

It will be important for mechanistic-empirical design methods to be able to accomplish a full evaluation of reliability, rather than simply handle it in an "overall" approach. Innovation in processes and materials will be easier to encourage when their impacts can be measured in terms of pavement's ability to provide long-term performance.

Be explainable to users

As with many technological issues, the ability to implement mechanistic-empirical pavement design will hinge on whether the



Monte Carlo simulation allows the user to evaluate the influence of input variability on the reliability of the design.

methodology is sensible and understandable to the users. A shift from empirical to mechanistic-empirical design will need to be done with a considerable amount of training. It should be constructed in a way that allows designers to relate their experience with the changes being made. The training should focus on the issues central to pavement design inputs:

- Traffic characterization
- Materials and soils characterization
- Seasonal fluctuation
- Layer thicknesses

To go along with the training, designers will need references such as an easy-to-follow design guide, a manual for traffic characterization, and documentation on typical material properties used in design.

Summary

Mechanistic-empirical design holds a great deal of promise in providing insights and tools for pavement designers. The ability to tailor a pavement to resist specific types of distress is a capability that has not been available previously. The ability to evaluate the impacts of changing loads, the quality of construction, and the introduction of new materials will be extremely valuable. In order to move forward with this valuable resource, much must happen during implementation to make it a reality. This article covered some of the crucial activities that should occur in the relatively short term. In the long-term, more improvements in mechanistic analyses will be made that will allow a better detailed understanding of pavement structures and offer even more opportunities for innovations. *HMAT*

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The previous *HMAT* articles on mechanistic-empirical pavement design can be found at www.hotmix.org/technology or in past issues of *HMAT*.

"Mechanistic Pavement Design: The Next Wave," *HMAT*, September/October 2001, pp. 49-51.

"Mechanistic Pavement Design: A Homogenized, Iceytropic Half What?," *HMAT*, January/February 2002, pp. 26-30.

"It's Still Dirt, Rocks, and Asphalt – Right?," *HMAT*, June 2002, pp. 16 – 22.

"Lies, Damned Lies, and Traffic Forecasting," *HMAT*, July/August 2002, pp. 14 – 21.

"Wanted: Transfer Functions – Experience Needed!," *HMAT*, December 2002, pp. 22 – 25.