

Research Project 0-4186  
“Cradle-to-Grave” Monitoring of Pavements and PMIS Functionality Enhancement Planning

Research Product 0-4186-P1  
**Definition of the  
“Cradle-to-Grave” Pavement  
Management Process**



Zhanmin Zhang, Randy B. Machemehl, Irfan Ahson  
Center for Transportation Research, The University of Texas at Austin

Roger Smith  
Texas Transportation Institute, Texas A&M University

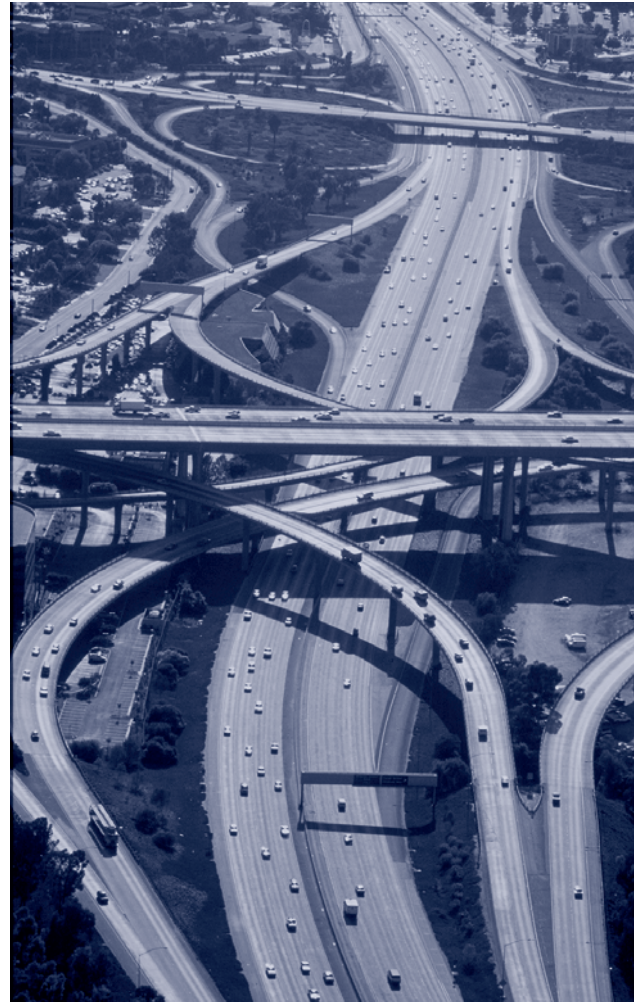
# Introduction

The highway transportation system is vital to the mobility of goods and people in Texas. Pavements are an important component of the highway transportation infrastructure, accounting for the single largest share of the overall investment in highway infrastructure. Because of the large network of highways in Texas, a tremendous amount of money is spent each year on the construction of new pavements and the maintenance and rehabilitation (M&R) of existing pavements. To maximize the benefits and minimize the overall costs associated with the process, a systematic and scientific approach is needed to manage the pavements. Pavement Management (PM) is the systematic process of planning, designing, constructing, operating, and maintaining pavements in a cost-effective manner; it combines solid engineering principles with sound business practices and economic theory to facilitate a more organized and logical approach to decision-making. A Pavement Management System (PMS), as opposed to pavement management, is composed of operational packages, including methods, procedures, data, software, policies, decisions, etc., that link and enable the carrying out of all the activities involved in pavement management.

The primary objectives of pavement management can be listed as follows:

1. Improve the condition of the pavement network
2. Maximize the performance of the network while keeping the costs to a minimum

The Pavement Management Information System (PMIS) is the automated portion of the PMS that has been used by the Texas Department of Transportation (TxDOT) to support the process of pavement management in Texas. Sometimes, the concept of pavement management has been regarded just as a software package used for man-



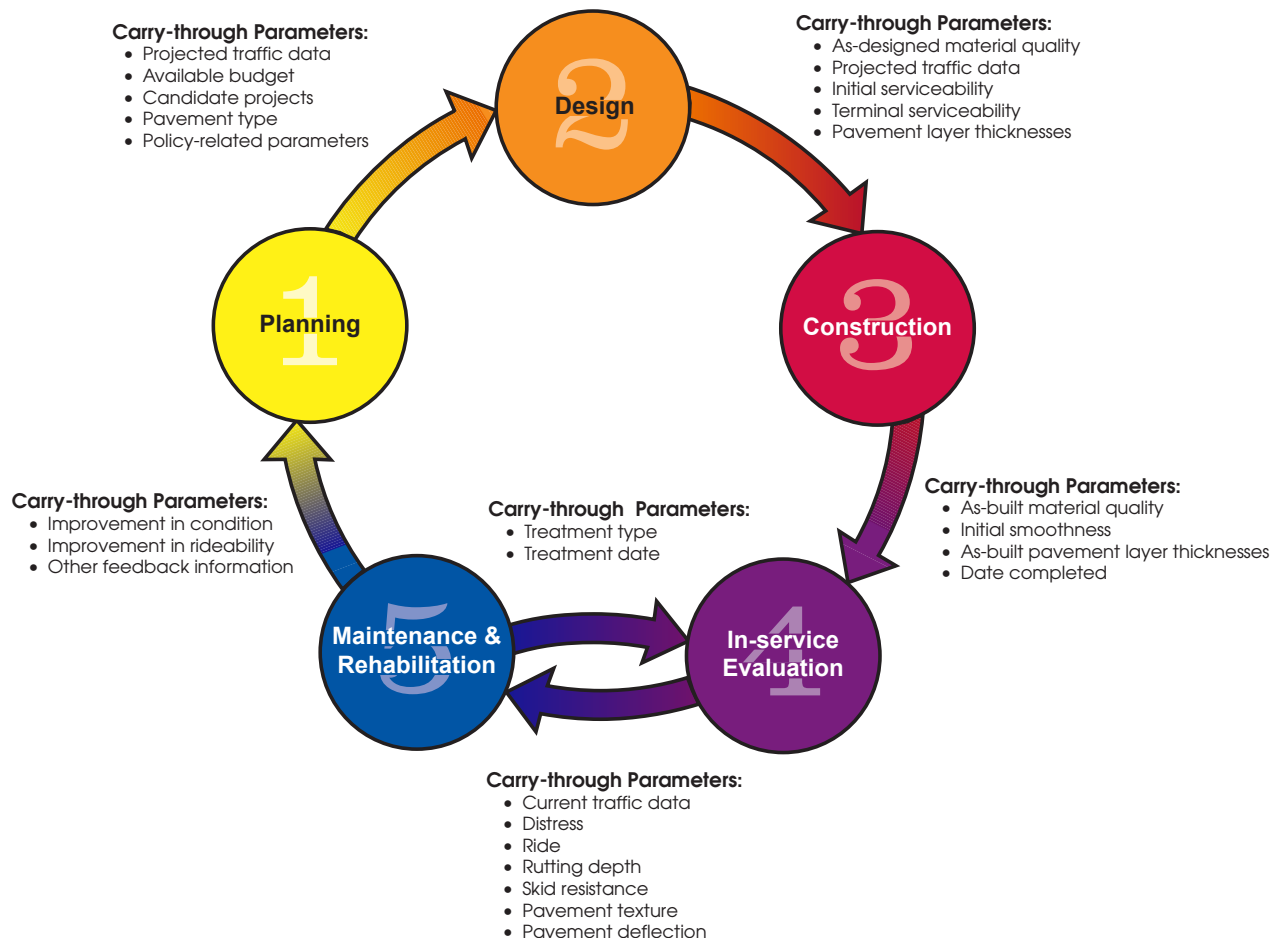
aging pavements, while it indeed represents a process much broader than the software usage. As implied in the definition given earlier, pavement management is in fact a process that starts from the conception of a pavement and continues through the life cycle of the facility. In other words, the process of pavement management encompasses all the activities associated with a pavement from the “cradle” to the “grave.” The concept of a comprehensive “cradle-to-grave” pavement monitoring and management is illustrated in Figure 1. For any pavement, the “cradle-to-grave” process goes through five major stages, namely:

- 1 Planning
- 2 Design
- 3 Construction
- 4 In-service evaluation
- 5 Maintenance and rehabilitation (M&R)

The life-cycle process has to be monitored and followed through all of the five major stages. The term “following through” implies that we have to design what was planned, build what was designed, monitor and evaluate what was built, apply M&R as needed based on the results from the evaluation, and finally assess what has been achieved as the feedback to the overall system.

For this objective to be achieved, we need to constantly monitor, record, use, and reuse certain parameters or testing values that are the key condition indicators of a pavement.

It must be realized that none of the five stages is isolated from the others; in fact, there is considerable overlap among them. For example, the output data from the design process becomes the input for the construction stage, and so forth. It is extremely important that this data flow, including any anomalies, is carefully documented throughout the pavement life cycle. The concept, “cradle-to-grave” monitoring and management” refers not only to the life-cycle stages that every pavement experiences, but also to the data and information flow associated with the overall life-



**Figure 1. Conceptual Framework of the “Cradle-to-Grave” Pavement Monitoring Process**

cycle process. This may include any assumptions and initial data that were used in the planning and design of the pavement, how and when the pavement was actually constructed (including any anomalies that occurred during the construction), what M&R treatments were applied across the life of the pavement (including cost data of these M&R treatments), adequate and up-to-date pavement performance data, and accurate traffic data for the pavement throughout its life. This entire, closely-monitored, cyclic process goes on across all the five life stages of the pavement, essentially leading to the concept of “cradle-to-grave” monitoring and management of the pavements”.

It must be emphasized that location reference information should be captured along with the pavement data and information to be collected during the “cradle-to-grave” process, as it will allow the comparison and correlation of the pavement information as it occurs along the roadway in the pavement management process.

A concise definition of the “cradle-to-grave” monitoring and management of pavements is therefore given as follows:

*““cradle-to-grave” pavement monitoring and management is the process of systematically collecting, efficiently maintaining, and effectively utilizing data and information that are critical to improving the performance of pavements for the life-span duration encompassing planning, design, construction, in-service evaluation, and maintenance and rehabilitation.”*



The planning process is the first stage of the life cycle for a pavement. It may be conducted for new construction, reconstruction, or major rehabilitation of

pavements. Extensive studies in policy-related issues and the collection of background data and information need to be undertaken at this stage. The data collected in the planning phase holds a very important place in the overall pavement management process. Preliminary traffic studies and future traffic projections are usually carried out to characterize the volume and composition of the traffic. Various competing candidate project options are considered and analyzed. The choice of the pavement type (i.e., flexible or rigid pavement) is also decided in the planning phase. This decision would entail performing geotechnical tests at the site, as well as evaluating the availability of suitable construction materials. Data used at the planning stage, despite its typical lack of detail, however, will prove valuable in the later stages of the pavement management process, such as the design stage. Policy issues such as the available budget and program goals are also carefully assessed. In short, a substantial amount of data, though not detailed in nature, is collected and processed to support decision-making at this stage. Ideally, the data collected in the planning phase should be carried onto the design stage, where it should be supplemented by more detailed data needed for a specific design. The key parameters that should be carried from the planning stage into the design stage include, but are not limited to:

- Projected traffic data (such as volume and axle loading)
- Available budget (in dollar amount)
- Candidate projects (such as locations and types of treatments)
- Pavement type (such as flexible vs. rigid)
- Policy-related parameters



Careful planning is the key to the success of any engineering project. Well-defined objectives and constraints supported by reliable background data and information in the planning stage lay the foundation for good engineering and successful management of pavement.



It is absolutely essential that, while carrying out the design, we maintain a clear picture of the original intent of the facility, which of course can be linked back

to the planning stage. The design of a pavement should serve as an extension of the planning objectives and should be centered on the parameters that were determined in the planning stage. The input of data collected during the planning stage is a vital aid in guiding the design process, regardless of whether it is a new pavement design or just a rehabilitation design. More detailed and thorough investigations have to be undertaken to support the specific design process. For instance, even though a decision on pavement type is made in the planning stage, much more detailed work is needed to develop a structural design of the pavement from section to section.

The design stage for a new pavement (or rehabilitation of an existing pavement) is a multi-objective and multi-criteria decision-making process where the determination of the pavement thickness and corresponding maintenance and rehabilitation (M&R) takes center stage. Usually, conflicting objectives arise while undertaking a design. While financial constraints are present, we also must consider other issues too, such as environmental impact. More often than not, we end up making tradeoffs between various competing issues. However, once all the input data values are prepared, a detailed design can be completed with the assistance of computerized design programs such as FPS-19W, CRCP-8, and AASHTO Guide.

Important output parameters or values from the design should be carried through and used as the control values for the quality control and quality assurance (QC/QA) during the construction stage. These parameters include:

- As-designed material quality (such as layer stiffness)
- Projected traffic data (such as volume and axle loading)
- Initial serviceability (such as the Present Serviceability Index (PSI))
- Terminal serviceability (such as the Present Serviceability Index (PSI))
- Pavement layer thicknesses

A good design serves as the basis for the successful construction of a pavement. It should be noted that even though the PSI is normally used as the measurement of the serviceability of a pavement during the design stage, the International Roughness Index (IRI) is frequently used as the measurement of the roughness or smoothness during and after the construction of the pavement.



Construction is one of the most important stages in the life cycle of a pavement. Even if we have done a perfect job in planning and designing a pavement, unless the actual execution of the design in the construction stage is carried out effectively, we are bound to run into problems. There are several parameters from the design and pre-construction stages that have to be followed through in the actual construction process to ensure that we are building what we have planned and designed. It is the duty of personnel at the site to ensure that the actual construction matches as closely as possible with the stipulated design parameters. For instance, if the as-built

strength of the pavement is lower than that used in the design, premature failures would likely occur. Variabilities in the construction process are not new. While every effort has to be made to reduce the variabilities through established QC/QA procedures, it is important that any anomalies be documented and monitored so that if there is a future problem it can be traced to its roots. To avoid the situation where a perfectly valid design is blamed for faulty construction practices, a reasonable amount of efforts and resources should be used to monitor the construction. In addition, sometimes the on-site conditions warrant a change or revision to the original design, resulting in the as-built section varying from the original design. The importance of tracking such changes with appropriate documentation cannot be overemphasized. Such documentation would be of great help in any forensic analyses. For instance, the subbase layer may have to be increased considerably if an especially weak stratum is encountered. Information documenting such a change would help in later forensic analyses, as well as aiding future efforts to produce appropriate rehabilitation strategies. The parameters that should be captured during or after the construction stage and carried through subsequent stages include:

- As-built material quality through lab or field tests (such as moduli)
- Initial smoothness (such as IRI measurements)
- As-built pavement layer thicknesses
- Date completed



The process of pavement management does not stop when the construction of the pavement is completed. Various monitoring, maintenance, and rehabilitation work are needed once the pavement is fully functional. Ideally, proactive approaches should be chosen over reactive approaches when it comes to pavement maintenance activities. To be proactive, periodic in-service evaluation should be conducted to monitor and evaluate the as-is performance of the pavement so that sufficient information can be available to project the future M&R needs. Furthermore, the accumulation of information from in-service evaluations would also contribute to the establishment of the pavement's history that is critical to the understanding of any problem associated with the pavement. When relevant data and information accumulated through in-service evaluation are recorded and readily accessible, the process of making informed decisions is greatly enhanced. Systematic data capturing, logging, and analyzing will ensure that the underlying root causes of problems are pinpointed and later remedied, rather than merely covered over.

There is a long list of parameters that should be monitored and evaluated when pavements are in service, but several ought to be collected on a regular basis and carried through the subsequent stages. These parameters include:

- Current traffic data (such as volume and axle loading)
- Distress (such as cracking and joint spalling)
- Ride (such as IRI measurements)
- Rutting depth
- Skid resistance
- Pavement texture
- Pavement deflection



Maintenance and rehabilitation is another important part of the life cycle of a pavement. Primary activities in this stage include the selection and prioritization

of candidate M&R projects, development of the best M&R strategies for each candidate project, and the scheduling of M&R activities for field operations. Obviously, the data and information gathered from the in-service evaluation would be crucial for decisions related to M&R. It should be understood that continuous and preventive maintenance prolongs the life span of a pavement considerably and is the preferred approach as compared to reactive maintenance measures. Another consideration in this stage is to understand the importance for eliminating the root causes of any underlying pavement problems, rather than merely resorting to cover-up measures. For example, a seal coat option would effectively cover up any cracks on the surface of the pavement for the time being, but the overall condition of the pavement may keep deteriorating if the fundamental reason behind the cracks is insufficient structural capacity. In such a case, an assessment of the structural adequacy of the pavement would be advisable to ensure that M&R strategies that do not enhance the structural capacity will not be used for pavements with inadequate strength. Of course, once the M&R work is completed, the overall pavement network performance and condition should be assessed to see if the goals or objectives that were originally set have been met. If not, additional M&R work may have to be put into the next cycle of the planning process. In other words, the performance and condition of the pavement network upon receiving the M&R work need to be compared to the target values that were set. The results from such a comparison should be used as feedback for the next cycle of planning. Some M&R parameters need to be carried back to the In-Service Evaluation to assist with that process including :

- Treatment type
- Treatment date

This “work history” information would help answer questions about how long specific types of treatments last.

Other parameters should be monitored in this stage and carried through to later stages including:

- The improvement in condition
- The improvement in serviceability
- Other feedback information

## Conclusion

As highlighted at the beginning of this document, the primary objectives of pavement management are: 1) to improve the condition of the pavement network, and 2) to maximize the performance of the pavement network while keeping costs to a minimum. The concept of the “cradle-to-grave” pavement monitoring and management process is critical to the fulfillment of the defined objectives. It should be emphasized that the “cradle-to-grave” process is cyclical; data collected at one stage and carried to the next stage would need to be available to all later stages. The cycle begins with planning of new construction, reconstruction, or major rehabilitation of pavements. It is this cyclical process with feedback information being carried through from one stage to the next that ensures that continuous improvement can be implemented in the pavement management decision-making. This would complete the life cycle in the “cradle-to-grave” process.

Research Project 0-4186  
“Cradle-to-Grave” Monitoring of Pavements and  
PMIS Functionality Enhancement Planning

Conducted for the



in cooperation with the



by the



Bureau of Engineering Research  
The University of Texas at Austin

March 2003  
Revised October 2003

## Acknowledgements

This project has been conducted under the guidance of, and has been directly assisted by the Project Director (PD), Stephen G. Smith of Odessa District, and Program Coordinator (PC), German Claros of the Research and Technology Implementation Office (RTI), Texas Department of Transportation. The authors also express appreciation to the following members of the Project Monitoring Committee (PMC) and TxDOT personnel for their generous support and guidance: Jim Freeman (former PC), Ahmed Eltahan (CST), Gerald Freytag (YKM), Darlene Goehl (BRY), Pat Henry (HOU), J. Tim Jennings (ISD), Magdy Mikhail (CST), Michael R. Murphy (CST), Elias Rmeili (BWD), Bryan Stampley (CST), and Andrew Wimsatt (FTW).