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# Keynote Presentation: Improving Pavement Sustainability through Integrated Design, Construction, Asset Management, LCA, LCCA, and S-LCA †

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**Abstract:** Engineers, planners, asset managers, materials suppliers, contractors, and policymakers are focused on improving pavement infrastructure sustainability, and increasingly considering climate change resilience. This focus is often on materials; however, the decisions and practices in design, construction, and asset management are typically more important in achieving the desired environmental, cost, and social outcomes. This presentation discusses the tools of mechanistic–empirical design, asset management, performance-related tests and specifications, construction quality assurance, environmental and social life cycle assessment, and life cycle cost analysis, which can be used together to achieve the desired outcomes, and the data and models of which can be integrated in efficient web-based systems.

**Keywords:** pavement; design; construction; asset management; life cycle assessment; life cycle cost analysis; social life cycle assessment; integrated data

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## 1. Introduction

"Sustainable" in the context of pavements refers to system characteristics that encompass a pavement's ability to [1] achieve the engineering goals for which it was constructed, [2] preserve and (ideally) restore surrounding ecosystems, [3] use financial, human, and environmental resources economically, and [4] meet basic human needs such as health, safety, equity, employment, comfort, and happiness [1]. Sustainability has always been the goal of pavement design, construction, and asset management, with a focus primarily on the engineering goal of handling motor vehicles, and the financial goal of minimizing either initial cost or life cycle cost.

The engineering goals of pavements have also been changing over the years, as knowledge and technology have changed, and as the definition of functionality has changed. As shown in Figure 1, 100 years ago, the focus was on measuring the subgrade bearing capacity and the additional structural capacity of different types of road building materials. The focus was on safely and efficiently carrying cars and trucks. The scope of pavement engineering expanded to pavement types and structures during the deployment of road networks, and then, once networks were deployed, attention turned to efficiently maintaining and rehabilitating the existing pavements considering the whole network, still primarily considering cost (mostly to the agency, but also to the user) in addition to the essential function of safety. Integration with other transportation networks, and a consideration of pavement work zone closures and other pavement-related disruptions on the efficient movement of goods and people, were added afterwards.

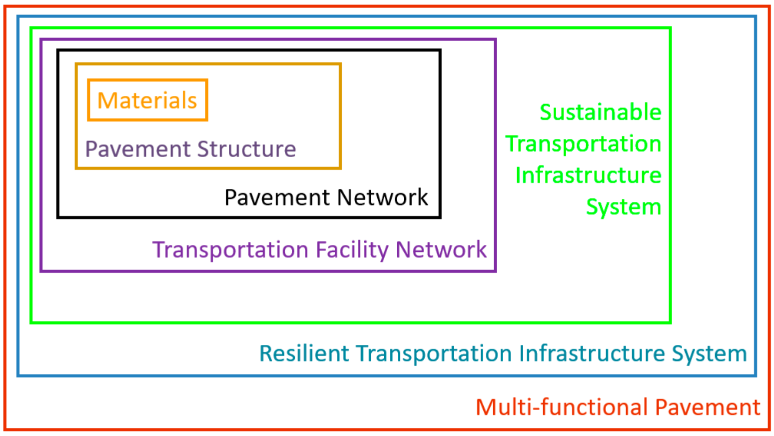


**Figure 1.** Changes in system boundaries for pavement functionality over last 100 years.

Today, and even more so in the future, networks and the pavements within them will need to achieve environmental goals, and resilience will need to be considered as climate change effects grow and as the requirements for maintaining or quickly restoring functionality during and after extreme precipitation, heat and cold events, and wildfires, for safety, economic, and quality of life reasons, becomes a requirement. In recent decades, it has become apparent that pavements have important environmental impacts and use large quantities of finite resources, which affects quality of life now and will have an increasing impact in the future. Nearly everyone in the world is also now aware of the effects of climate change and there are increasing efforts in every sector of the economy to reduce greenhouse gas emissions and reach net zero emissions, with varying target dates for reaching that goal. There are now market signals for the private sector to compete with in terms of reducing environmental impact, and governments at the local, state, and national levels are similarly sending market signals, setting goals, and using various methods to achieve those goals.

The functionality required of pavements, particularly in urban areas, is also changing to increasingly include active transportation, stormwater pollution mitigation, stormwater and sea level rise flooding risks, human comfort and safety in extreme heat events, and noise.

New tools have been developed to support pavement decision-making through the life cycle and for the wider definitions of the complete system to meet these changing requirements for planners, engineers, asset managers, constructors, and policymakers. These have included tools for pavement materials testing and design, structural design, asset management, life cycle cost analysis, environmental life cycle assessment, and construction quality. New tools are being developed to consider the social effects of access to good pavements, and the social effects of the extraction, processing, and construction of materials. Often, these tools do not communicate with each other in terms of data, models, terminology, and reporting, effectively siloing their use and requiring replication effort to build, support, and use them. Paying attention to the data is essential to using the tools that have not always been well-designed, and insufficient attention, effort, and resources are often applied for maintaining up-to-date and comprehensive data and models.

The pavement is long-lived infrastructure, with very few roads ever abandoned. The pavement life cycle includes planning, design, construction, preservation, maintenance, rehabilitation, reconstruction, and end-of-life, with many loops back into the cycle. Environmental sustainability, cost sustainability, and, increasingly, social sustainability are best and most efficiently achieved by considering the full life cycle and the complete system, which also helps avoid negative unintended consequences.

## 2. Overview of the Presentation

This presentation reviews the types of tools used in pavements and the requirements for well-planned and -executed processes for building and maintaining the data and models that make them most useful. Figure 2 shows the "pyramid" concept, emphasizing that the majority of the cost, effort, and attention need to be on the data; in the case of a PMS, the models required are for pavement performance prediction and cost which then support life cycle costing and budget optimization. It discusses an approach being implemented in California to develop integrated data definitions and frameworks, databases, models, and web-based tools to support pavement decision-making through its life cycle. This presentation reviews the different stages of the life cycle where environmental sustainability can be improved and their relative importance for different types of roadways. It also reviews how cost and social sustainability can be considered using the integrated tools, and how this integration helps produce better results more efficiently. Several examples are given as follows.

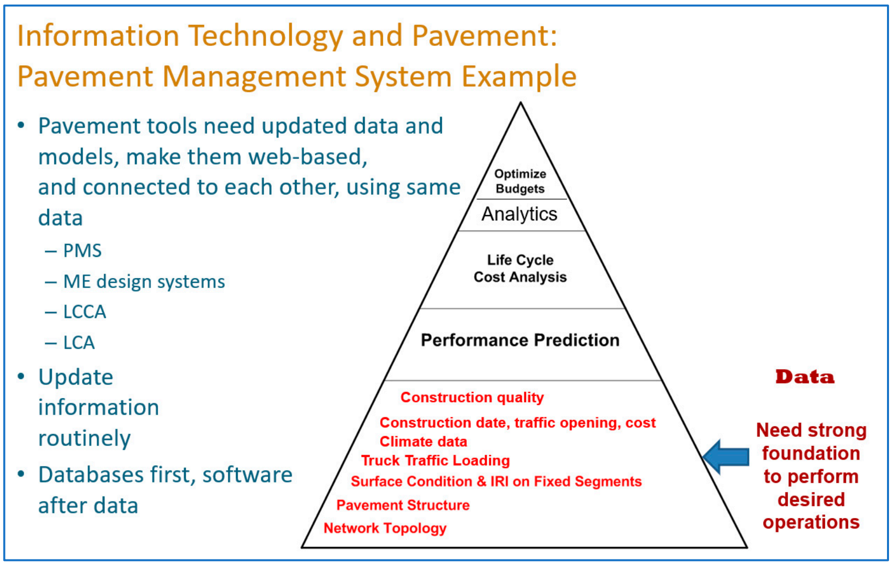


**Figure 2.** Example of "pyramid" concept for PMS, emphasizing that data, then models, are priorities to support the tool.

## 3. Calibration of Mechanistic–Empirical Structural Design Methods Using Asset Management Data

This example looks at the recent calibration of the California ME design methods for asphalt and concrete surface pavements using hundreds of thousands of observations from the asset management system, and performance-related materials testing data [2].

## 4. Improved Life Cycle Cost Analysis Using ME Design and Asset Management Results

This example looks at the recent updating of the California LCCA tool using the results of ME simulations for cracking and roughness performance models of the pavement management system.

## 5. Environmental Life Cycle Assessment Using Materials Data, ME Design Results, Construction Quality Data, and PMS Models

This part of the presentation presents an overview of life cycle assessment, the California LCA tool eLCAP [3], and the use of materials designs, ME design simulation results, and roughness models from the PMS to quantify environmental impacts over the life cycle, as well as the use of cradle-to-gate LCAs called environmental product declarations (EPD) in construction material procurement. Another example uses PMS models for age-related cracking and materials data to evaluate the effects of asphalt compaction, and a third example compares the use of preservation treatments vs. rehabilitation-only treatments with respect to life cycle cost and life cycle emissions.

## 6. Environmental Impact Analysis in the PMS and Prioritization of Strategies Using Life Cycle Assessment and Life Cycle Cost Analysis

The implementation of LCA in the pavement management system to calculate global warming potential is illustrated with an example. Another example looks at an approach called the marginal cost of abatement curve, or "supply curve", for assessing the cost effectiveness of different strategies for reducing environmental impacts [4].

## 7. Integration of Social Vulnerability into Decision Support

The initial steps and applications for the consideration of social vulnerability and environmental impacts in asset management are the final examples shown for integrated tools.

## 8. Summary

The functional requirements and system boundaries for pavements have increased, and the need for tools considering the full life cycle and complete system in order to support decision making in this more complex environment has also grown. Those tools need to be supported with comprehensive, up-to-date, high quality data and models. This presentation shows examples of the development and use of integrated web-based decision support tools to help meet these challenges.

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