CENTENNIAL PAPERS

Standing Committee on General and Emerging Pavement Design (AFD30)
Gerardo Flintsch, PhD, P.E., Chair

General and Emerging Pavement Design

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ABSTRACT

A Transportation Research Board (TRB) of the National Academies of Science, Engineering and Medicine (NASEM) Standing Committee on General and Emerging Pavement Design was created in 2016 primarily to address aspects of and approaches to pavement design and rehabilitation universal to pavements of all types and challenges for pavements not fully compatible with traditional asphalt or concrete pavement design assumptions and models. Various institutions have handled unconventional designs, innovative materials, and unusual construction or installation practices in the paradigm of standard designs and processes, thus inadvertently stifling innovation and achieving less than optimal benefits. Sustainably has metamorphosed from a vague concept and evolved to an extent that requires quantification and certain proof of adherence to standards for reducing the carbon footprint. Technological advancements, intelligent materials and vehicle systems, and the growing awareness of a need for pavement multi-functionality that addresses storm water quality, flood control, thermal, and other environmental factors, have triggered the need for a home for innovations and deployments in this rapidly growing area of pavements. This centennial paper provides a brief review of the development of pavements to meet sustainable and multi-functional design criteria in addition to the structural requirements that govern design in the modern era. The paper reviews the beginnings of unconventional pavement designs and current initiatives, and looks forward toward how this TRB committee is positioned to respond to these changing needs and be a forum for developing sustainable, practical, and functional pavement designs of the future.

INTRODUCTION

Background

Creating Transportation Research Board (TRB) Standing Committee AFD30 in 2016 marked the beginning of a push for nodal housing for research and initiatives in new and emerging pavement design. This committee recognizes that the factors responsible for its creation and the terms of reference by which it operates are based on both historical and recent design innovation and a vision for future designs to meet a wider range of future needs than current pavement design and analysis approaches seek to deliver.

Historical Motivations for Pavement Design

It is suggested that the Romans, who built 60,000 miles (96,000 kilometers) of roads, adopted the idea of a road system from the Carthaginians [1] with the original impetus of military maneuvers. The Roman road design generally consisted of four layers (top to bottom) as follows [2]: (1) summa crusta (surfacing): smooth, polygonal blocks bedded in the underlying layer; (2) nucleus: a kind of base layer composed of gravel and sand with lime cement; (3) rudus: a third layer composed of rubble masonry and smaller stones also set in lime mortar; and (4) statumen [2]: two or three courses of flat stones set in lime mortar (pozzolanic material) with a total thickness of as much as 1 meter (39 inches). In the late 18th century, Thomas Telford built roads on relatively flat grades (no more than 1 in 30) in order to reduce the number of horses needed to haul cargo. Roads then enabled efficient cargo hauling. Further, the pavement section was about 350 to 450 mm (13.8 inches to 17.7 inches) thick and generally composed of three layers. John McAdam introduced the use of smaller angular stones in the early 19th century, and his roads were referred to as being "macadam" [3]. On top of these stones was placed the wearing course, which was about 50 mm (2 inches) thick with a maximum aggregate size of 25 mm (1 inch) [4]. McAdam's reason for the 25 mm (1 inch) maximum aggregate size was to provide a "smooth" ride for wagon wheels. By 1903, pavement thickness had reduced from the Roman 1 m (39 inches) to Telford's 0.5 m (19.6 inches) and McAdam's 0.15 m to 0.25 m (6 inches to 10 inches) as efficiency in design materials and economic factors influenced pavement design. McAdam also advocated for paid full-time professional engineers to be responsible for the construction, management, and maintenance of road systems.

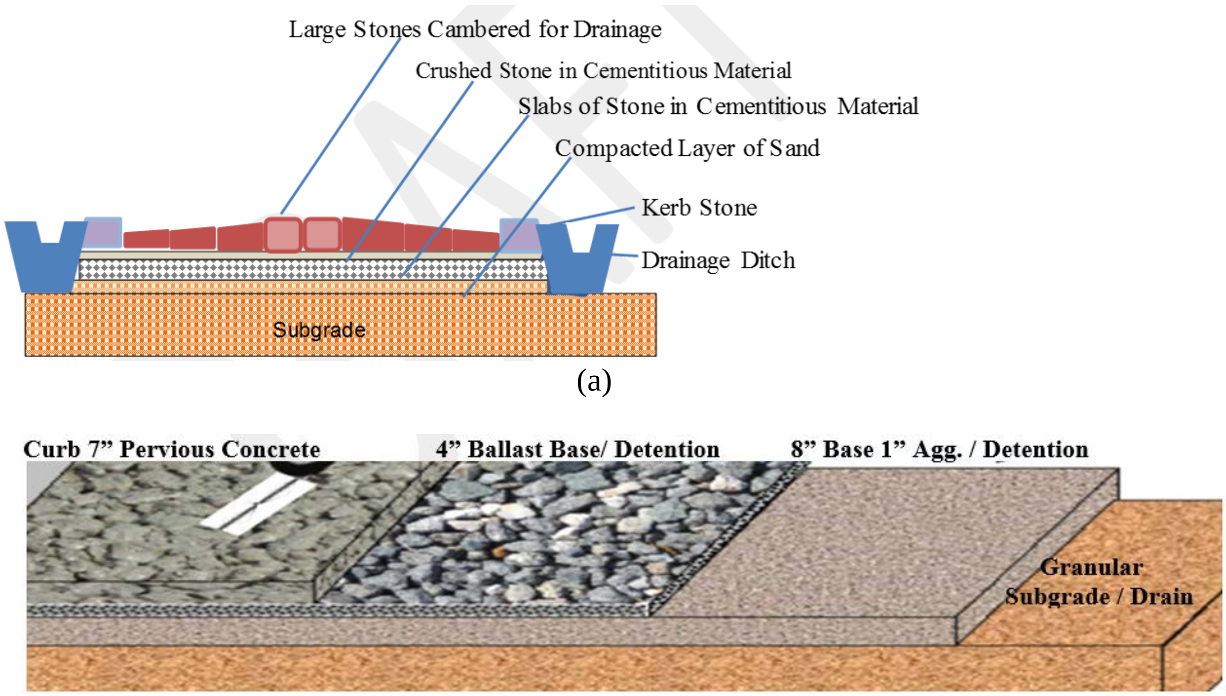
Coal tar (the binder) was available in the United Kingdom beginning around 1800 as a residue from coal-gas lighting. The Nottingham tar macadam project using waste products as "aggregates" represents the earliest recycled modern aggregate pavements [5] (the Romans almost certainly recycled stone used for other purposes for their roads). In 1871, in Washington, D.C., a "tar concrete" was extensively used. Sulfuric acid served as a hardening agent and various materials, such as sawdust, ashes, etc. were added to the mixture [5]. In part, due to lack of attention in specifying the tar properteis, most of the paving projects failed within a few years of construction, leading to a gradual development of material specifications in asphalt pavements. In the late 19th century, asphalt was imported from Trinidad Lake to the eastern states for road construction. In the western states, asphalt was produced locally from the refining of pretroleum.

The first roads made of portland cement concrete were built at the end of the 19th century, using portland cement, which was patented in 1824. A 1916 report by Agg and McCullough [6] to the Iowa State Highway Commission attributed poor performance of the earliest concrete pavements to low compressive strengths, poor inspection, poorly prepared subgrade, inadequate mix design, mixing, consolidation and curing of the portland cement concrete, as well as failure to achieve adequate strength gain prior to opening streets to traffic. These are still the issues that construction specifications and special provisions guard against today.

The philosophical conceptual difference in today's designs is a higher level of design for functionality to improve human quality of life beyond just mobility, which requires greater consideration of multi-functionality in addition to, but not instead of, structural considerations. The other conceptual difference is the understanding that, as roads have become one of the most widespread industrial operations in the world, and as population and wealth growth have increased demand for roads, change is desperately needed to move more rapidly towards achieving some measure of sustainability. Greater movement towards sustainability is needed to slow the rate and effect of climate change, and to conserve finite natural material resources as well as protect air, land, and water quality. The preponderance of functional requirements over structural requirements has thus become clear.

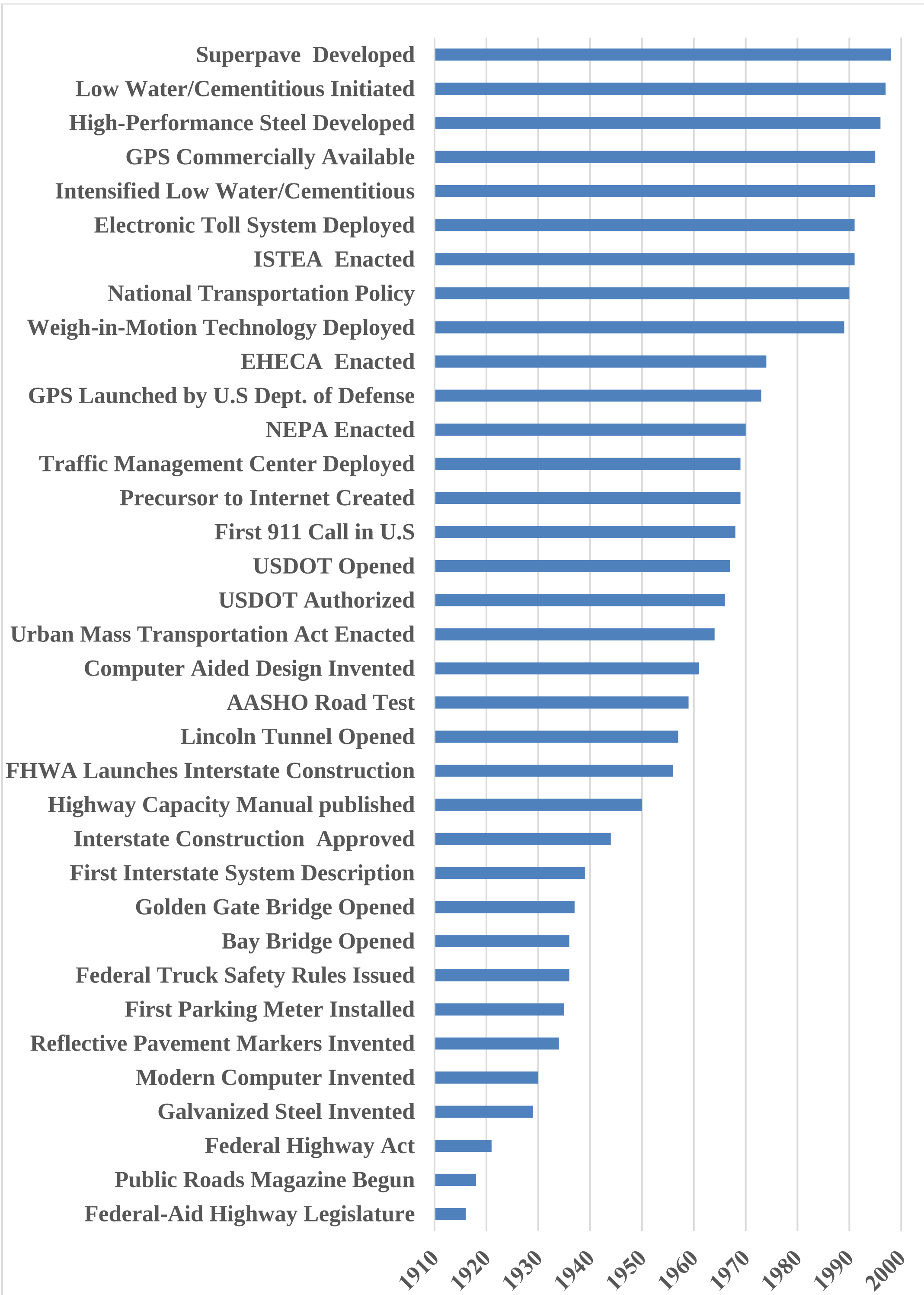
Functional Characteristics as a Paradigm Change in Pavement Design

Figure 1 shows conceptual designs of a first century AD [2] Roman roadway and a 2012 emerging MnROAD (Minnesota's Cold Weather Pavement Testing Facility) deployment of pervious concrete pavement. The conceptual designs are structurally similar. Pervious concrete was designed to function as a load bearing structure, a storage detention system with the pore volume of the base and subbase, a drainage structure with the porosity of every layer of the structure, and as a high friction surface. It was also designed as a geothermal structure fostering dynamic equilibrium between the deep subgrade soil temperature and the surface, thus minimizing the need for snow and ice activities. The major difference between a typical innovative pavement structure and the archaic Roman or Carthaginian road lies in multifaceted functional characteristics, as we expect pavements to do more than just carry traffic loads. Additionally, as shown in Figure 2 and Figure 3, most historical developments were generally material and structural. The last decade of the last century and the early part of this century saw the development of better measurement techniques. These techniques helped to improve the standard for construction and multifunction ranging from bus shoulders to photovoltaic and potentiometric pavement designs. The late 1970s, development of the International Roughness Index (IRI) by the World Bank followed by IRI standardization in 1995 [8], and subsequent release of the Federal Highway Administration's (FHWA's) Profile Viewer and Analyzer (ProVAL) software are partly responsible for smoother paving. Similar observations have been associated with the International Friction Index (IFI) and load transfer efficiency.



(b)

Figure 1: (a) Roman Road in the first century; (b) Section through a pervious concrete section in the MnROAD Research Facility AD 2012.



Superpave Developed
Low Water/Cementitious Initiated
High-Performance Steel Developed
GPS Commercially Available
Intensified Low Water/Cementitious
Electronic Toll System Deployed
ISTEA Enacted
National Transportation Policy
Weigh-in-Motion Technology Deployed
EHECA Enacted
GPS Launched by U.S Dept. of Defense
NEPA Enacted
Traffic Management Center Deployed
Precursor to Internet Created
First 911 Call in U.S
USDOT Opened
USDOT Authorized
Urban Mass Transportation Act Enacted
Computer Aided Design Invented
AASHO Road Test
Lincoln Tunnel Opened
FHWA Launches Interstate Construction
Highway Capacity Manual published
Interstate Construction Approved
First Interstate System Description
Golden Gate Bridge Opened
Bay Bridge Opened
Federal Truck Safety Rules Issued
First Parking Meter Installed
Reflective Pavement Markers Invented
Modern Computer Invented
Galvanized Steel Invented
Federal Highway Act
Public Roads Magazine Begun
Federal-Aid Highway Legislature
1910
1920
1930
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Figure 2: Summary of a century of major pavement events. (EHECA=Environmental Highway Energy Conservation Act; NEPA = National Environmental Protection Act).

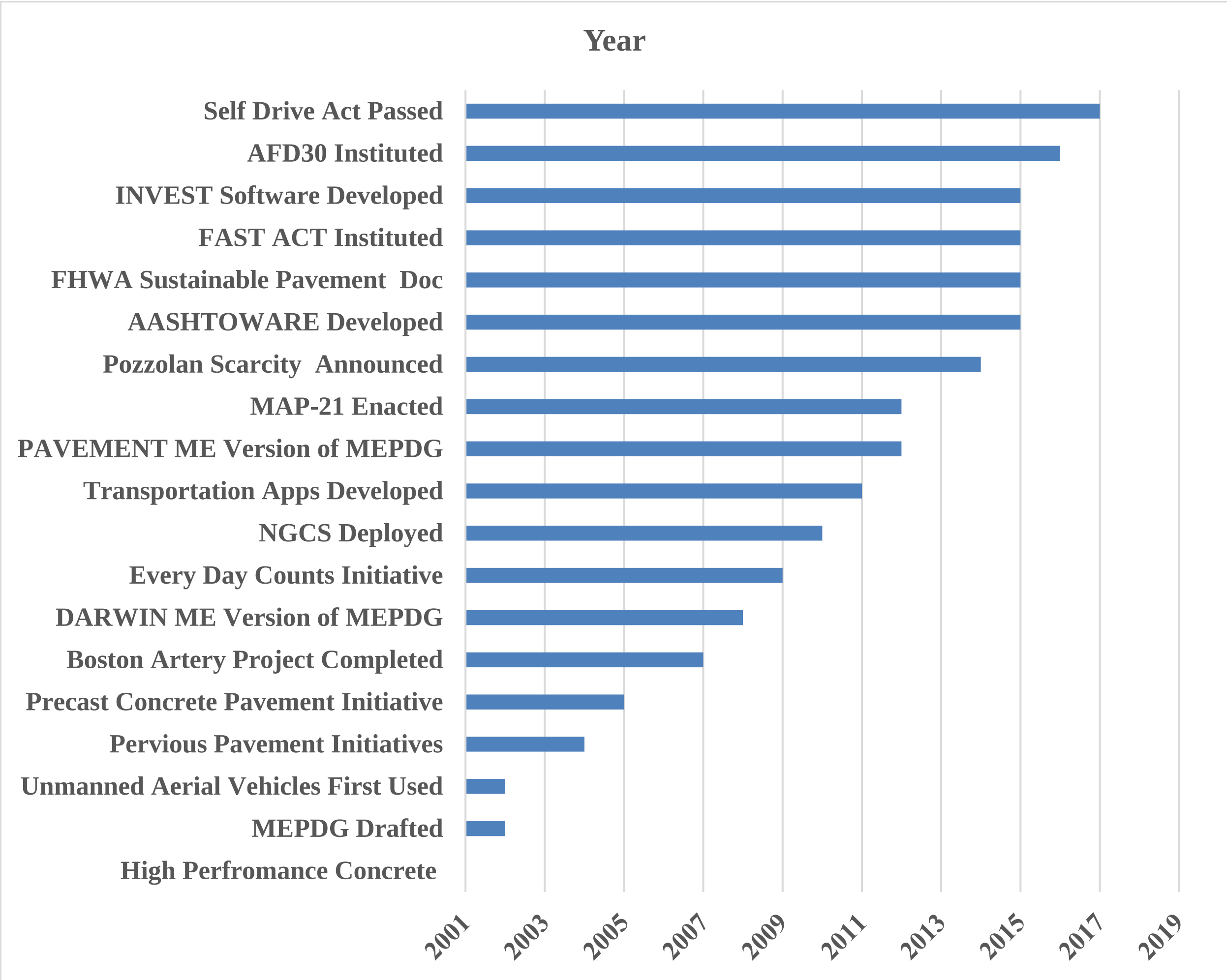


Figure 3: Summary of key milestones in the 21st century.

SUSTAINABILITY AS THE MAJOR PARADIGM CHANGER

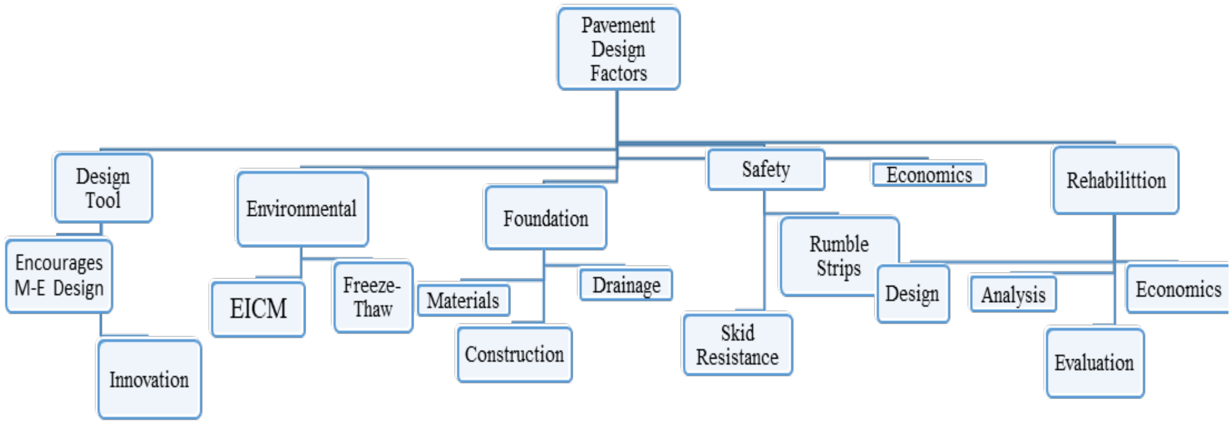
The Office of Road Inquiry was established in 1890 as interest in bicycle riding grew. It became the Bureau of Public Roads in 1915, the Public Road Administration in 1939, and the FHWA in 1966. The American Association of State Highway Officials was established in 1910 (with "Transportation" added in 1973). The introduction of mass-produced automobiles early in the 20th century and subsequent reliance on fuel taxes for road funding led to a focus on vehicle travel, and the design, construction, and maintenance of pavements for vehicular travel.

The FHWA set the objectives of sustainability in pavement design first in 1999 [9] and in 2017 [10] disseminated *Sustainability Requirements in Pavement Design*. While the earlier directive focused on structural and, to some degree, functional characteristics, there was still a need to include sustainable objectives (Figure 4). The latter set of design requirements introduced detailed functional performance indices, as well as the use of life cycle assessment

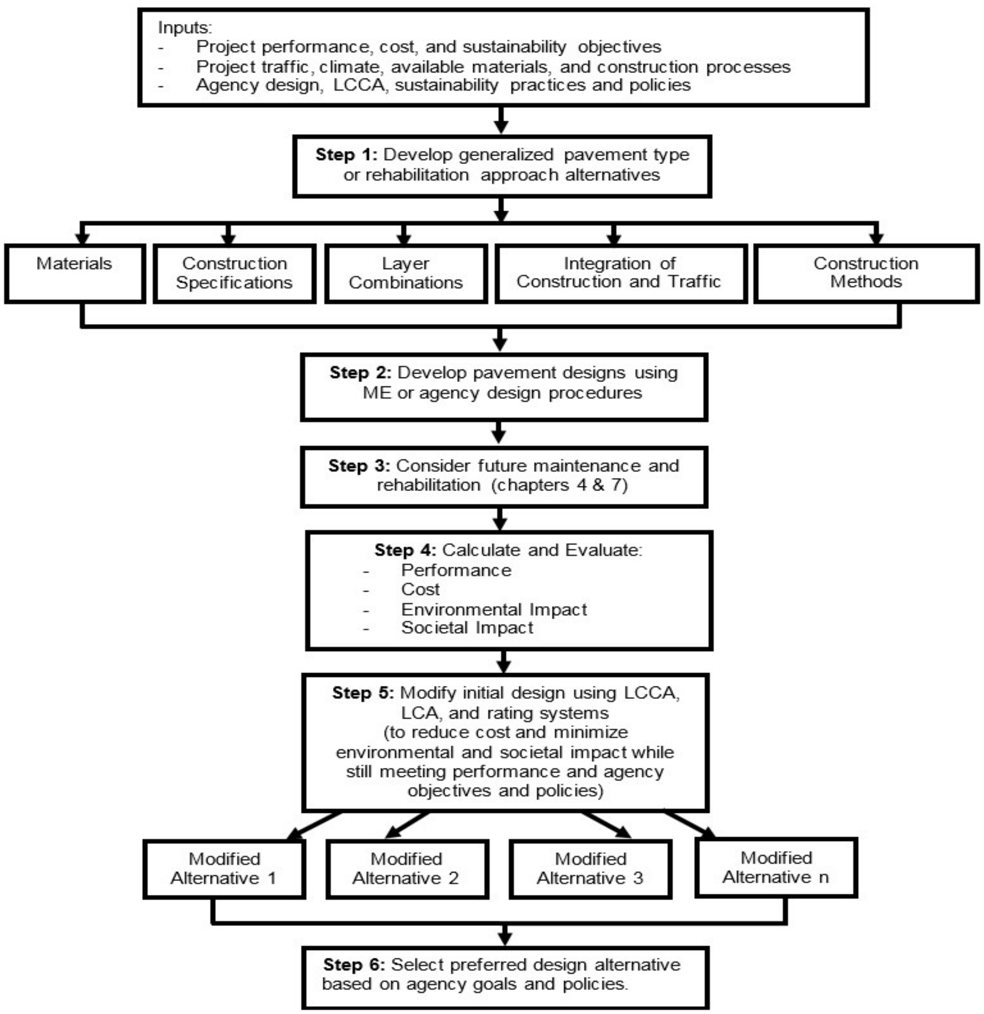
(LCA) and life cycle cost analysis (LCCA) to the pavement design process, although the widespread use of LCCA in design had been a federal highway focus since the 1990s.

Advent of Sustainable Development

In 1989, the Bruntland Commission on Environment and Development identified the need for sustainable development [11]. Whereas the commission was hard pressed for a working definition, the report [11] listed a number of characteristics that make a project sustainable. They summarily defined sustainable development as that which fulfils all the initiatives of today without jeopardizing the ability of current sister states, nations or people groups, and future generations from fulfilling their initiatives. Deconstructing the paradigm, they identified the three salient facets as “environmental,” “economic,” and “quality of life/performance” sustainability. Environmental sustainability includes, but is by no means limited to, reclaiming, reusing, and recycling to minimize use of finite resources and forestall environmental impacts.



4a. Intent of pavement design [9].



4b. Overall process for considering sustainability in pavement design. Culled from FHWA Document [10].

Figure 4. FHWA Flow Chart of 1999 design objectives and 2015 design objectives and process.

Environmental sustainability minimizes the impact of the road system on the surrounding hydrologic and biological environmental systems. Quality of life is enhanced when roads are efficient in safe conveyance of people, goods, and services without adversely impacting human comfort both for road users and those affected by the road and its use. Economic sustainability pertains to fiscal strategizing by individuals, agencies, and governments to provide the service of the road in balance with other demands for financial resources now and in the future. Therefore, taking steps to plan for a secure, financial future, while protecting the local economy and the economies of others ensures economic sustainability. Since the 1989 commission, various countries, agencies, and especially the FHWA, have intensified sustainable development efforts. The following are examples of such efforts around the globe.

1) Introduction of the use of LCA into the pavement community to identify goals and systems, and quantify environmental impacts and finite resource use in the Netherlands in the 1990s, and in other parts of Europe afterward. Subsequent widespread application of the process in the late 1990s led to the conferences on Pavement LCA first held in 2010 and continuing forward.
2) Request for Environmental Product Declaration (EPDs) in Europe and initial requirements for EPDs in the US (California Department of Transportation and High Speed Rail Authority). The relevant standard for EPDs is ISO 14025 [12]
3) Development of qualitative assessment metrics for sustainability exemplified in the FHWA Infrastructure Voluntary Evaluation Sustainability Tool (INVEST) software.
4) Increased use of supplementary cementitious materials in cement and concrete pavement.
5) Increased recycling of asphalt binder through higher percentages of reclaimed asphalt pavement (RAP).
6) Intensified soil reinforcement and use of non-woven fabric as stress relief layer.
7) Thinner pavement designs based on:
    a) Fiber-substituted mix designs (Roessler Atoulbat, Lederle, et al.) [14] [15] & [17].
    b) Use of non-woven geo-fabrics instead of porous bound granular stress relievers such as PASSRC.
    c) Enhanced capacity due to reduced shrinkage facilitated by low water/cementitious ratio, high pozzolan substitution, and well graded aggregates.
    d) Enhanced drainage designs and drainable pavements [18].
8) Enhanced LCA and LCCA tools [19].
9) Better and more efficient construction practices resulting in smoother ride quality.
10) Increased use of new materials and products intended to reduce environmental impacts, either through replacement of existing materials or longer life, which requires less frequent replacement, also reducing environmental impact. An example is reclaimed tire rubber to modify asphalt properties, and use of supplementary cementitious materials.
11) Awareness coming from use of “life cycle thinking” based on LCA principles that not all change is positive, and that positive changes in a small area of the system or life cycle can lead to larger negative unintended consequences elsewhere in the system or later, and that use of LCA and LCCA can help avoid these unintended consequences [19].
12) Efficient concrete matrix based in well graded aggregate, low water/cementitious ratio, and high pozzolanic substitution [20].
13) Intensified use of in-place and side-of-the road reclamation of existing pavement materials, including full-depth-reclamation, cold-in-place recycling, and cold central plan reclamation.

14) Focus on the use of thinner pavements and rehabilitation treatments through improved construction quality and better materials and structural designs.
15) Understanding of the role of pavement preservation in extending the life of expensive and environmentally impactful structural designs through timely interventions.

These developments were a clear indication to TRB that the industry has experienced an avalanche of introductory use of innovative non-conventional materials and designs. Consequently, TRB leadership realized that a committee would be required to address these issues in a holistic way.

ESTABLISHMENT OF A RELEVANT COMMITTEE

The proposal for a new standing Committee on General and Emerging Pavement Design (AFD30) was crafted by the emeriti of the AFD70 committee in 2016. The proposal addressed the purpose of the committee, general scope need, relationship to other committees, and relationship to other organizations.

Need and Objective

The most significant finding from the strategic review of the TRB Pavement Management Committee (now AFD00) was that there were a number of cross-cutting pavement design topics that did not then have an "institutional home" within the existing TRB organizational structure. To address this gap, several potential organizational structures for the Pavement Design Section were considered and discussed at some length by the Section Executive Board and the committees comprising the section. The outcome of the discussion was unanimous agreement to adjust the scopes of the two existing pavement design committees (Flexible Pavement Design [AFD50] and Rigid Pavement Design [AFD60]) to encompass pavement rehabilitation approaches that are consistent with traditional rigid and flexible pavement design theories and approaches, sunset the existing Standing Committee on Pavement Rehabilitation (AFD70), and establish a new Standing Committee (AFD30) to address cross-cutting pavement design and rehabilitation topics and issues.

Scope

This committee is concerned with the theory, design, rehabilitation, and performance of non-traditional pavement systems and analytic approaches and tools that apply to all pavement types. Areas of interest include all factors that influence the economic impacts, resiliency, and environmental sustainability of pavement systems.

Examples of cross-cutting pavement design considerations include pavement type selection, LCCA, and consideration of sustainability. Additionally, many pavement design challenges are not fully compatible with traditional asphalt or concrete pavement design assumptions and models (e.g., asphalt layers on concrete pavement, segmental concrete pavements, or pavements constructed with materials not relying on asphalt or cement as a major structural layer, not including gravel roads). Consideration of multi-functionality beyond motorized vehicle movement to include active transportation, and to consider that pavement has significant effects on flood control, storm water quality, thermal environments, climate resilience, air pollution, and noise, as examples, is also a charge of this committee. Since none of the existing standing committees was scoped to address the more cross-cutting pavement design and rehabilitation issues, to date, some (but not all) cross-cutting issues had been addressed through the formation of Group or Section-level subcommittees. While these subcommittees were productive, this approach was not viable as a comprehensive solution. A more appropriate solution was the creation of a cross-cutting pavement design and rehabilitation committee scoped to address cross-cutting and emerging pavement design needs in a cohesive fashion.

Anticipated Accomplishments

The committee was designed, in the long term, to develop research needs statements and sponsor sessions, workshops, and other technology transfer efforts addressing needs—including pavement type selection, LCA, LCCA, and sustainability—of pavements, design of pavements not fully compatible with current rigid and flexible pavement design theories (including rehabilitation), design of segmental concrete pavements, and design of pavements constructed with non-traditional materials. Also considered is development of "universal" pavement design methodologies, applicable to pavements comprised of any combination of traditional or non-traditional materials, and integration of design, construction, maintenance, and rehabilitation, including consideration of financing arrangements other than the traditional design-bid-build.

AFD30 VISION FOR THE FUTURE

AFD30's mission is to help define the vision for pavements of the future and support and promote the work necessary to achieve that vision. As noted previously in this document, the vision for pavements of the future can be summarized as encouraging and enabling the design of pavements that are safer, more sustainable, multi-functional, and often unconventional. Examples include fully permeable pavements for mobility; storm water quality and flood control; segmented concrete pavements; innovative uses of asphalt and cement; damaged pavements reclaimed in-place or at the side of the road; pavements to serve active transportation and new dimensions of vehicular traffic, including automation and electrification; and pavements that help provide thermal and aural environments that support human quality of life.

This vision includes new approaches for increasing the speed and productivity of pavement technology improvement. The vision also includes the development of processes that can be widely used for assessing changes for environmental and financial sustainability, and for assessing the feasibility of new pavement ideas to help focus resources on those that offer the most financial and environmental promise and the least unintended consequences. To help achieve this vision for the future, AFD30 will consider myriad performance data from most state and local networks. While these data sets are not from controlled experiments as would be sourced at test tracks, new approaches for analysis that can make reliable and efficient use of these data need to be developed. This will offer the potential for substantial improvements in pavement management and design. With better data collection and analytic capacity, it is now possible to observe service life trends and create more representative models towards better service life prediction and design considerations. AFD30 will lead pavement technology initiatives and be a repository and/or clearing house for performance trends that will help with life cycle costs and assessment in alliance with the AFD20 Standing Committee on Pavement Monitoring and Evaluation.

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