CENTENNIAL PAPERS

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James Greene, Chair (AFD40)

Accelerated Pavement Testing: Celebrating over 100 Years of Innovation and Economic Benefits

BOUZID CHOUBANE, *Florida Department of Transportation*
JAMES GREENE, *Florida Department of Transportation*

INTRODUCTION

The evaluation and validation of new/emerging pavement technologies and innovative concepts require assessing their in-service long-term performance. In-service assessment requires the consideration of the interaction between traffic loading, materials properties, and environmental effects. The primary disadvantage of such an evaluation approach is the extensive time period required to obtain potentially meaningful results. Additionally, it is often difficult, impractical, and/or expensive to obtain or account for all the factors required from in-service experimental set ups.

The need for faster and more practical evaluation methods under closely simulated in-service conditions prompted the consideration of accelerated pavement testing (APT). APT is generally defined as a controlled application of a realistic wheel loading to a pavement system simulating long-term, in-service loading conditions. This allows the monitoring of a pavement system's performance and response to accumulation of damage within a much shorter time frame. APT can cost-effectively produce early, reliable and beneficial results while improving pavement technology and understanding/prediction of pavement systems performance.

The following provides a brief historical overview and perspective of the evolutionary milestones that APT has experienced.

EARLIER EFFORTS

Detroit Circular Test Track - 1909

In 1909, the Public Works Department of Detroit, Michigan, constructed what was considered the first pavement test track *(1)*. This track, of circular shape, was built to test different sections of paving materials that included concrete, granite, creosote block, and cedar block. A crude device, referred to as "Paving Determinator" was used for loading. It consisted of heavy iron-rimmed wheels mounted on one end of a 20-foot pole and a set of steel horseshoes on the other end, as to simulate horse and wagon traffic of the day. Based on the subsequent results, Wayne County, Michigan, paved Woodward Avenue with concrete, as shown in Figure 1, at a total cost of $13,492.83 *(2)*. According to the American Concrete Pavement Association (ACPA), that was the first mile of rural concrete in the United States. Sixty more miles of concrete roads were built in Wayne County in the following two years.

FIGURE 1. Paving Woodward Avenue in 1909 (Michigan in Pictures)

The subsequent report of the 1914 National Conference on Concrete Road Building contained over 260 pages of guidelines on all aspects of concrete pavement design and construction *(3)*. By then, the discovery of the hot vulcanization of rubber made it possible to manufacture solid rubber tires *(4)*. The Roads Act of 1920 not only increased the maximum empty weight of a “heavy traction engine” from 15 to 17 tons but also the travel legal speed to 12 mph from 5 mph if equipped with rubber types instead of steel wheels *(4)*.

Bates Road Test - 1920

In 1920, the State of Illinois allocated approximately $100 million for the paving of a primary road system. To this end and in order to provide the Illinois Division of Highways information on and understanding of rural pavement design (determining rational pavement layer thicknesses, minimizing the variable factor of subgrade bearing capacity, etc.), a two-mile test road was built *(5)*. It ran from Bates, IL (SW of Springfield) east to Farmingdale Road on what is now the old US-54. This test road, commonly known as Bates Road Test, consisted of six groups of test sections, each representing a given type of pavement of variable thicknesses and strength. Each of these group of sections consisted of the following paving materials: (1) vitrified brick surfacing with bituminous joint filler on a macadam base; (2) vitrified brick with bituminous joint filler on a concrete base; (3) asphalt surfacing on a macadam base; (4) asphalt surfacing on a concrete base; (5) "monolithic" brick, or brick with cement grout filler laid on a concrete base; and (6) one-course concrete, both plain and with various inclusions of embedded steel. The test road was trafficked with Liberty trucks, U.S. Army vehicles produced during World War I with dual 5-inch solid rubber tires on the rear axle Trafficking of the test road with Liberty trucks is shown in Figure 2 *(6)*. The subsequent findings led, for instance, to the use of a longitudinal center joint to eliminate longitudinal cracking in concrete pavements. Until then, many pavements were built with no joints and a thickened center section in an attempt to prevent the formation of erratic longitudinal cracks. The results were also used by Older to develop an equation relating pavement thickness to traffic loading based on the theory of cantilever beams *(1, 5)*. The Associated Press reported in 1926 that the Bates Road tests saved the state an estimated $9 million in construction costs. Bates Road has since been reconstructed and is now a part of the State Highway System.

FIGURE 2. Liberty trucks trafficking the Bates Road Test *(6)*

Pittsburg Road Test - 1921-22

About the same time period, test loops known as the Pittsburg Test Road, shown in Figure 3, were built off of the roadway between Pittsburg and Antioch, California. The Pittsburg Test Road was sponsored by Columbia Steel Company and its main purpose was to determine the benefits of using reinforcing steel in concrete pavements. As documented in reports such as that shown in Figure 4, it included thirteen test sections ranging from 5 to 8 inches in thickness, including thickened edges, various levels of steel reinforcement, longitudinal joints, and instrumented slabs. The intent of thickened edge sections (edges 2 in. or 3 in. thicker than the center), prevalent at that time, was to compensate for the higher corner or edge stresses that occur due to wheel placement location. Here also, old World War I Army trucks with solid tires were used for loading. The subsequent results were inconclusive as the debate on reinforcement still remains unsettled to this day. However, it was determined that critical stresses were at the corner of the slabs and simple equations relating pavement thickness to traffic loading were developed *(7)*.

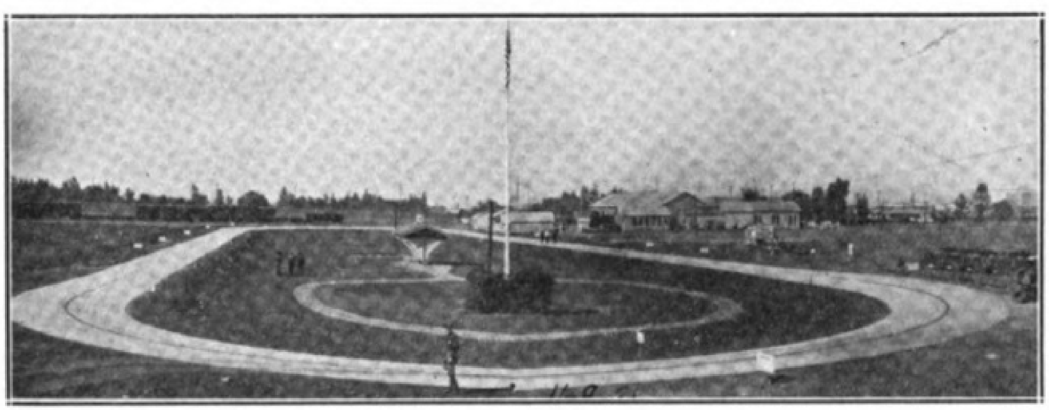

FIGURE 2.
GENERAL VIEW OF COMPLETED—TEST HIGHWAY.

FIGURE 3. Test Loop from Pittsburg Road Test

Findings from Early APT Efforts
These early APT efforts, based on the Bates and Pittsburg test roads showed that a pavement service life is related not only to the magnitude and frequency of wheel loads but, also to its characteristics and substrate. It further showed the importance of the environment conditions. Several design equations were proposed separately by Goldbeck, Older, and Sheets *(1)*. In 1930, a PCA publication Design and Construction of Concrete Pavements adopted Older's equations *(7)*. These were the beginnings of so-called "mechanistic-empirical" design procedures.

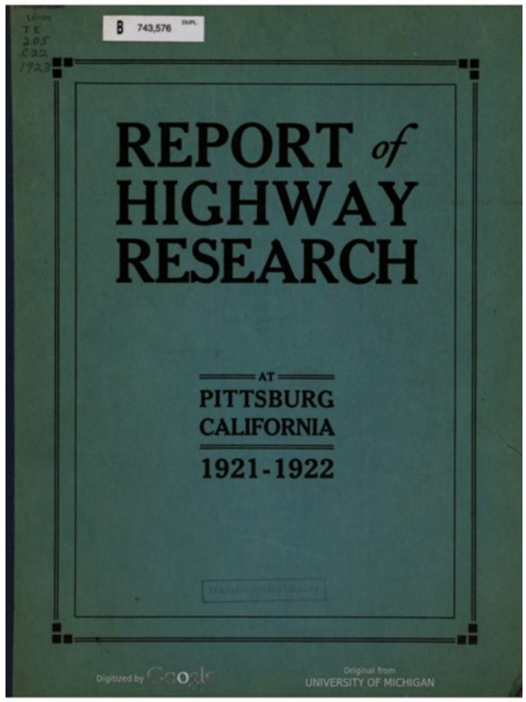

FIGURE 4. Highway Research Report on Pittsburg Road Test

ADVENT OF PNEUMATIC TIRES AND VARIED AXLE LOADINGS

The types of loads and wheels subjected to the pavements continued to evolve. By mid 1920s, the use of pneumatic tires, pioneered by Goodyear, started to become more prevalent *(9)*. By that time, Goodyear also led the development of several other important trucking concepts including tandem axles, dual wheel assemblies, and the fifth wheel system for trailering *(9)*. As such, and according to the Public Roads Administration in 1949, the traffic not only considerably increased but varied both in magnitude and frequency. In addition, the 1944 Federal-Aid Highway Act provided a framework for highway improvements in the postwar. All these served as a motivation for further road tests. Maryland Road Test was therefore, proposed by the Interregional Council on Highway Transportation in December of 1949.

Maryland Road Test - 1951-52
The principal objective of the Maryland Road test was to gain insight into the load carrying capacities of concrete pavements for pavement design purposes as well as for framing potential legislation to govern highway operations *(10)*. It was sponsored by 11 Midwestern and Eastern states as well as the District of Columbia and administered by the Highway Research Board of

the National Academy of Sciences. The road was a 1.1-miles section of concrete road on US-301, approximately 9 miles south of La Plata in Southern Maryland. The 24-ft wide pavement was reinforced and divided with a longitudinal joint. The thickness of each 12-ft lane was 7 inches at the center and 9 inches at each of the edges. The section was subjected to around the clock trafficking using four different axle loadings (rear single axle trucks loaded to 18,000 and 22,400 lb. per axle and rear tandem axle trucks loaded to 32,000 and 44,900 lb. per tandem). The more significant findings included the definite correlation between soil type and pavement performance as well as the impact of pumping on cracking and faulting *(10, 11)*.

The Transport Committee of the American Association of State Highway Officials (AASHO) further promoted additional projects. AASHO believed that these additional tests considering other conditions including different pavement types were necessary for a comprehensive understanding of pavement behavior and design. Plans were developed for Southeastern Association of State Highway Officials (SASHO) and the Western Association of State Highway Officials (WASHO) each to consider bituminous-type road tests and the Mississippi Valley Association of State Highway Officials to initiate another concrete project.

WASHO Road Test, Idaho - 1952-54

The WASHO Road Test, through the participation of 13 western states, was constructed near Malad City, Idaho. Similar to that of Maryland Road Test, the principle purpose of this test was to determine the relative effects of four different axle loadings on asphalt pavement sections. The test sections consisted of two different thicknesses (2 and 4 inches) of asphalt pavements over various thicknesses of granular base *(12)*. The subsequent results showed the major impact of freeze-thaw on pavement performance and the benefit of paved shoulders *(13, 14)*. In addition, a pavement deflection device, known as the Benkelman Beam (named after its developer AC Benkelman), as well as an asphalt overlay design procedure based on in-situ deflection measurements were developed at the WASHO Road Test *(13)*.

The Historical AASHO Road Test, 1956-61

The AASHO Road Test is often cited as the first modern test road and is probably the most comprehensive and largest controlled highway experiment ever undertaken *(14)*. It consisted of six two-lane loops constructed along the alignment of Interstate 80 near Ottawa, Illinois, 80 miles southwest of Chicago. It was sponsored by the American Association of State Highway Officials (AASHO) and, as in the case of Maryland and WASHO Road Tests, administered by the Highway Research Board of the National Academy of Sciences. The main objective was to investigate the performance of various pavement structures and conditions under moving loads of known magnitude and frequency *(14, 15)*. It considered both concrete and asphalt pavements, as well as certain types of short-span bridges. The Department of Defense provided heavy vehicles for traffic loading *(14, 15)*.

The information from the AASHO Road Test ended up being quintessential to substantially advancing the knowledge and understanding of pavement performance and design. It introduced many significant and long-lasting concepts including (1) the serviceability concept, (2) the load equivalency factor, (3) structural number (SN) concept, (4) construction variability effects, and (5) effectiveness of dowels and joint spacing *(16, 17)*. Ultimately, in 1961-62, AASHO issued respective interim guides for the design of flexible and rigid pavement structures *(18, 19)*. Thereafter, the guides were subsequently updated, first, as *AASHO Interim Guide for Design of Pavement Structures in 1972 (20)*, then, as *AASHTO Guide for Design of Pavement*

Structures in 1986 and 1993 (21). The 1993 version of the guide is still widely used. An FHWA article celebrating its 50th anniversary stated that "the AASHO road test in Illinois was a landmark in highway and bridge design that has never been equaled".

RENEWED INTEREST

During 70s and 80s, more APT programs, mainly fixed facilities, were initiated mainly outside the US. Significant activities were reported from counties like Australia, South Africa, Spain, Denmark, France, Britain, and Netherlands *(22)*. It was reported that, as of 1979 as many as 31 programs/facilities were in operation and actively contributing to the advancement of pavement technology *(22)*. Some of these programs are briefly described below:

South Africa Program

The oldest known fixed facility program was established in 1968 in South Africa. This effort was primarily motivated by the need to develop a pavement design procedure to suit the country local conditions. The program used the first linear loading device, known as the Heavy Vehicle Simulator (HVS). This fixed HVS was manufactured from Bailey Bridge components to simulate the damage done to airport runways due to aircraft landing gear impact. This led to the South African Mechanistic Design method *(24)*. However, the need to also use it for testing in-service pavements throughout South Africa prompted the subsequent development of the first fully mobile self-powered HVS in 1970 *(25)*. The HVS can apply wheel loads of up to 45 kips using dual or super-single tires at speeds of up to 10 mph. The device provides for uni- or bi-directional load application with or without wander. In 2004, it was reported that the quantifiable benefits resulting from this program to be estimated at about $17 million per year *(26)*.

New Zealand Program

Similarly to South Africa, New Zealand pavement design and construction practices are fundamentally indigenous. The highway traffic is carried primarily on thin-surfaced asphalt pavements. The need to ensure that such pavements are adequate prompted New Zealand to construct its first accelerated loading facility in 1969. The latter was subsequently decommissioned in 1987 and replaced by a new and improved indoor one referred to as the Canterbury Accelerated Pavement Testing Indoor Facility (CAPTIF) *(27)*. Located near Christchurch International Airport, CAPTIF is housed in a hexagon-shaped building. The test track is confined to a 5- ft deep and 13-ft wide circular concrete pit with moisture control capabilities. The dynamic loading is applied, at speeds up to 30 mph, using a system known as the Simulated Loading and Vehicle Emulator (SLAVE). SLAVE has two arms and can accommodate, single, wide single and dual-wheels as well as single to tandem-axle bogies travelling on separate wheel paths.

Australia Program

The Australian Accelerated Loading Facility (ALF) was first commissioned at the 68th meeting of the National Association of Australian State Road Authorities (NAASRA) *(28)*. It was driven by the need to research pavement materials and pavement structure performance as well as the economics of road vehicle limits. The ALF applies uni-directionally loads from 8,800 to 17,600 lb through a dual-tire single-wheel assembly. The driven rolling wheel is applied to pavement test sections 40-ft in length at a constant speed of about 12 mph. The loading can either be channelized or transversely distributed over a width of up to 4ft.

France Program

In 1984, an outdoor full-scale test track was built at the Laboratoire Central des Ponts et Chaussées (LCPC), (now French Institute of Science and Technology for Transport, Development and Networks (IFSTTAR)), near Nantes *(29)*. With an inner diameter of 100 ft and an outer diameter of about 130 ft., it is considered one of the largest circular fixed loading facilities in operation. Its loading simulator, referred to as the Manège de Fatigue or pavement fatigue carrousel, is a four-arm rotating loading system. The end of each arm can be equipped with different loading wheel assemblies and axle configurations (single or twin wheels attached to single, tandem or tridem axles). These wheels can also move laterally to simulate traffic wander. Loads of approximately 9,000 to 16,000 lb can be applied at speeds of up to 105 km/h (65 mph). As an illustration of the resulting benefits, LCPC stated that the findings from the inverted structure motorway experiment alone saved approximately $100,000 per km compared to the standard construction and that the cost of the carousel was practically written off in less than 5 years *(c)*.

The Netherlands Program

With the primary objective of improving pavement response and damage models, an accelerated pavement testing program was commissioned at the Road and Railroads Research Laboratory of Delft University of Technology (TUDelft) in late 1980s. In this linear facility, known as LINTRACK, the testing can be conducted at speed of about 12 mph using single, dual, or super-single wheel with loads ranging from 3,300 to 22,000 lb. The total loading length is about 12 ft and can be distributed transversely 3.2 ft each side of the centerline. The whole loading assembly is mounted on rails across a 180 ft-long test area. In addition, the test sections can be constructed by conventional equipment *(23)*.

The research conducted at LINTRACK focused on the validation of empirical and theoretical models for rutting and cracking in flexible pavements, the evaluation of the damaging effects of various wheel configurations and the performance evaluation of innovative pavement structures.

Spain Program

A major outdoor loading facility was built at the Road Research Center (Centro de Estudios de Carreteras CEC) near Madrid. The center is part of the Center for Public Works Studies and Experimentations (Centro de Estudios y Experimentacion de Obras Publicas (CEDEX)), managed by the Ministry of Public Works Transport and Environment. The oval track consisted of two parallel straight stretches, each 245 ft long, joined by two semi-circular segments with a radius of 82 ft. The load testing sections are confined to a 8.5- ft deep and 26-ft wide concrete pit with moisture control capabilities along the straight path. The loading is applied by two bogies, each guided by a rail beam located on the inside perimeter of the track. The gravitational axle loads, ranging from 24,000 to 33,000 lb., can be applied at a speed of up to 37 mph. Pavement instrumentation is monitored from a control center that also operates the two vehicles. Standard construction equipment and procedures are used *(23)*.

APT RESURGENCE

The 1990s was the beginning of a renewal and resurgence of APT programs with major investment not only in the US but worldwide *(22)*. Although the investment primarily focused on fixed facilities, there has also been a few full-scale test roads. By 2012, it was reported that as many as 43 APT programs were actively conducting research (*30*). Illustrative examples of both facility types are given below:

Full-Scale Test Roads

MnROAD - 1990

MnRoad was the first full-scale pavement test track since the AASHO Road Test of the early 1960s. In the 1980s, the Minnesota Department of Transportation (MnDOT) explored the idea of a Cold Regions Pavement Research Test Facility. This led, in 1990, MnDOT, in partnership with the Minnesota Local Road Research Board, to construct a full-scale pavement test facility known as MnROAD. MnROAD, constructed at a cost of $25 million, is located 40 miles northwest of Minneapolis-St. Paul, near the town of Albertville along Interstate 94. It consists of over 50 distinct test sections, each representing various combinations of paving materials and designs, on a 3.5-mile stretch of I-94. Within each of these test sections, over 4500 sensors were installed to comprehensively monitor the pavement response and to collect environmental data. In-service highway traffic is used for loading by diverting the westbound traffic on I-94 onto the test section *(22)*. A bypass is provided to shift traffic off the mainline testing segment when needed for more detailed evaluation. In addition, a 2.5-mile section looping through the facility is set as a low volume road test. A semi-trailer truck is used for loading in this case.

Since its construction, MnRoad has been the site of a number of significant pavement engineering experiments. It has also been used as a demonstration or test site for pavement-related equipment.

WesTrack - 1994-99

In 1987 Congress passed the Surface Transportation and Uniform Relocation Act, authorizing a major highway research program. This program, known as the Strategic Highway Research Program (SHRP), was a five-year, $150 million research endeavor. One of its more significant deliverable was the Superpave mix design method introduced in 1992. This mix design method was designed to improve the design, performance, and materials selection of asphalt mixtures. As a follow on then, in 1994 the Federal Highway Administration (FHWA) sponsored, through the National Cooperative Highway Research Program (NCHRP), the design and construction of a hot-mix asphalt (HMA) APT facility, known as WesTrack. Its primary aim was to quantify the construction impact on performance and to validate Superpave *(31)*. The 1.8-mile oval track was located approximately 60 miles southwest of Reno, Nevada. Each tangent contained 13 test segments, 230-ft in length, each with distinct mixture designs and/or construction requirements. The loading was performed with 4 driverless (autonomous) trucks with tractor-triple-trailer combinations and 20,000-lb. axle loads.

WesTrack was essential primarily in (1) advancing the development of performance-related specifications (PRS) for HMA pavements by evaluating the impact on performance of deviations in materials and construction properties (namely, asphalt binder content, aggregate gradation, aggregate type, and in-place air void content) from design target values, and (2) providing an early field verification/validation of the SHRP Superpave design method.

Furthermore, it proved valuable in forensic analysis and pavement failure investigation and provided a path for tests of autonomous truck controlling systems *(32)*.

National Center for Asphalt Technology (NCAT) Pavement Test Track - 2000
In 2000, the National Center for Asphalt Technology (NCAT) completed the construction of an oval test track. NCAT was established at Auburn University in 1986 with an endowment set up by the National Asphalt Pavement Association's (NAPA) Research and Education Foundation. Its mission is to "Improve asphalt pavement performance through research, education, and information services".

The 1.7-mile track is located on a 309-acre site in Lee County, Alabama, approximately 20 miles from Auburn University. It consists of 46 test sections, each 200 ft. long with different experiment set up, funded as a cooperative project among highway agencies and industry sponsors *(33)*. The traffic is applied with triple-trailer trucks. In addition, the track also provides opportunities for various non-pavement materials related projects such as the evaluation of new heavy vehicle suspension systems, alternative fuels, and improved vehicle electronics and safety.

Furthermore, in an effort to consider colder climate conditions, NCAT has partnered with the Minnesota DOT for parallel or complementary testing at MnROAD. NCAT and MnROAD are currently the nation's two largest full-scale pavement testing facilities. Such a partnership will certainly provide unique opportunities to more comprehensively address important national issues and challenges.

Florida Concrete Test Road - 2020
In 2016, Florida initiated the construction a 2.5-miles concrete test road that is expected to open to real world traffic in late 2020. It will allow for a comprehensive in-service performance assessment of new/emerging concrete pavement technologies and innovative concepts while giving a full consideration to the interaction between factors such as traffic loading, design features, materials properties, construction practices, and environmental conditions.

The test road is being constructed parallel to an existing roadway (northbound segment of US-301 in Clay County) to allow traffic to be diverted from the test road back to US-301 periodically for performance monitoring without impacting the traveling public. It will be unique in that it is the only full-scale concrete pavement test facility of this type in the Southeastern United States. A facility of this type, coupled with its already well-established and well-recognized Accelerated Pavement Testing (APT) program, will definitely set forth the Florida Department of Transportation (FDOT) as a worldwide leader in innovations and advancement in pavement engineering knowledge and practices.

Fixed Facilities
Since the 1990s, a number of APT fixed facility programs have and continue to be implemented worldwide. At the time of this writing, at least one new program is being initiated in Argentina. The following is a brief description of some of these facilities. One has to note though that the experimental pavement sections built at some fixed facilities may not always be typical or representative of in-service pavements. Also, this is a non-exhaustive list of the existing facilities and is only provided to illustrate the types and diversity of facilities. More detailed information could be found elsewhere *(23, 26)*.

US Federal Highway Administration (FHWA) - 1986
The FHWA's APT program was established in 1986 as part of its Turner Fairbanks Highway Research Center in McLean, VA. Two ALF machines, based on the Australian design, are operated at the facility. The first machine was acquired in 1986 and the second was added in 1995 *(23)*. The 100-foot long device runs a weighted wheel assembly across a pavement surface in one direction, for a duration of ten seconds, then returns the wheel to the starting position, and runs it across the surface again. The loaded wheel simulates one rear dual-wheel of a typical truck.

Indiana - 1992
In 1992, the Indiana Department of Transportation (INDOT), in association with Purdue University, initiated an APT program. The APT facility is located at the INDOT Division of Research and Development in West Lafayette. It is housed in a 2,000 square feet environmentally-controlled building comprising a test pit, loading mechanism, and control and monitoring equipment. The pavement test tracks are constructed on a 20 feet x 20 feet x 6 feet deep pit with full control of water table. Pavement can be constructed using conventional equipment. Pavement may be heated internally up to about 120^{o}F with cooling control capabilities. Loads of up to 20,000 lbs. are applied using a dual wheel or a super-single half-axle assembly at 5 mph either uni- or bi-directionally *(34)*.

California - 1994
In 1994, the California Department of Transportation (Caltrans) established an APT program through the purchase of two refurbished HVS from South Africa *(23)*. This program was initially a collaborative effort between Caltrans, the University of California, Dynatest Consulting, Inc. and the South African Council for Scientific and Industrial Research (CSIR). The APT program is currently part of the University of California Pavement Research Center at Davis with a dedicated facility and two HVSs.

Louisiana - 1995
Louisiana built a pavement research facility 5 miles south of Baton Rouge, just across the Mississippi River. It is operated by the Louisiana Transportation Research Center, a joint venture between the Louisiana Department of Transportation and Louisiana State University. The site includes nine parallel lanes constructed using full-scale construction equipment and closely model normal highway construction. The loading is performed using an ALF, similar to that of FHWA *(23)*.

Ohio - 1997
The Ohio Accelerated Pavement Load Facility (APLF) was constructed in 1997 as a joint venture between Ohio University and Ohio State University, through a grant from the Ohio Board of Regents. The enclosed facility, located on the Ohio University Lancaster campus, provides space for construction of two lanes of pavement and monitoring under various loading and environmental conditions.

Finland and Sweden (VTT & VTI) - 1997

In 1997, the Technical Research Center of Finland, the Finnish National Road Administration, and the Swedish National Road and Transport Research Institute (VTI) initiated a joint APT program referred as the Nordic APT. They jointly acquired an HVS Mark IV as a loading machine.

US Army Corps of Engineers - 1998

In 1998, Engineer Research and Development Center of the US Army Corps of Engineers initiated a full-scale pavement test facility dedicated solely to airfield pavement research. The loading device is a heavy HVS, known as HVS-A. This HVS was designed to use dual aircraft wheels with loading capacity of up to 100,000 lbs.

US Federal Aviation Administration - 1999

In 1999, the US Federal Aviation Administration (FAA) initiated a full-scale pavement test facility dedicated solely to airport pavement research referred as the National Airport Pavement Test Facility (NAPTF). Located at the William J. Hughes Technical Center near Atlantic City, New Jersey, its construction was completed in April 1999 with the establishment of the Cooperative Research and Development Agreement between the FAA and Boeing *(26)*. This facility allows for the testing through simulated undercarriages of aircraft weighing up to 650 tons. The Pavement Testing Machine spans two sets of railway tracks that are 76 feet apart. The vehicle has adjustable dual-wheel loading modules. The load is applied to the wheels on the modules through a hydraulic system.

In addition, in order to assess the impact of high tire pressures and wheel loads rather than the gear loads on asphalt pavements, FAA also acquired the world's largest Heavy Vehicle Simulator, referred as HVS-Mark VI Airport, in 2013. According to the FAA website, the trend in aircraft industry is to produce aircraft with extended range capability, which results in high gross weight and tire pressures. This 21-feet long, 16-feet wide, and 14-feet high heavy HVS is capable of applying bi-directional and unidirectional loading using a single wheel (maximum wheel load of 100,000 lbs) or dual wheel gear (maximum wheel load of 50,000 lbs.). It can also accommodate a lateral wander pattern up to a maximum wander width of ± 3 feet (total wander 6-feet compared to 3-feet for a standard HVS). The associated facility, part of the FAA National Airport Pavement and Materials Research Center (NAPMRC), has four outdoor and two indoor test lanes.

Florida - 2000

The Florida Department of Transportation (FDOT) initiated an APT program in early 2000. The APT and research program is based within the State Materials Research Park in Gainesville. The testing site consists of five linear test tracks each measuring approximately 450-foot-long by 12-foot-wide, and three additional tracks measuring approximately 150-foot-long by 12-foot-wide. There are additional two test tracks designed with water-table control capabilities within the supporting base layers.

The construction of the test tracks for any experiment complies with all standard FDOT construction and materials specifications and methods. The accelerated loading is performed using a Heavy Vehicle Simulator (HVS), Mark IV+ model acquired in 2000 *(35)*. In 2017, FDOT acquired a second HVS, a Mark VI model.

The APT program has become a significant component of FDOT's implementation-focused pavement research program and has been providing critical information to policy makers. Significant savings have been directly attributed to the implementation of APT research results. It has been conservatively estimated that over $4 million was saved in 2011 as a result of research and implementation of polymer modified asphalt binders and fine-graded asphalt mixtures. In addition, more than $35 million has been saved since changes in pavement design practices and construction specifications based on APT findings have been implemented *(37)*. Furthermore, in its first ten years of its existence alone, eight Ph.D. dissertations and one Master's thesis have been completed using Florida APT data *(37)*.

Illinois - 2002

Through funding from the Illinois Department of Transportation, the Advanced Transportation Research and Engineering Laboratory (ATREL) at the University of Illinois at Urbana-Champaign (UIUC) built an APT facility in 1993 *(34)*. The site is located 15 miles north of the main campus. The accelerated loading is performed using a system known as the Accelerated Transportation Loading System (ATLAS). It is capable of simulating aircraft, truck, or rail traffic distributions. ATLAS weighs 156 kips and is 124 feet long, 12 feet high, and 12 feet wide. Mounted on four crawler tracks, it transmits loads to the pavement structure through a hydraulic ram attached to a wheel carriage, which can accommodate a single tire, dual tires, aircraft tire, or a single axle rail bogey. The maximum load level is 80 kips at testing speed of up to 10 mph. The loading can be either uni- or bi-directional with optional wheel wander of up to 3 feet. ATLAS can apply up to 10,000 repetitions per day.

Switzerland - 2006

The Swiss program was initiated at the Swiss Federal Laboratories for Materials Science and technology, or EMPA, Duebendorf, in 2006. The associated loading machine is known as the Mobile Load Simulator (MLS)-10. It consists of a 33-foot long space frame housing four-wheel bogies, each fitted with dual 295/65 R22.5 truck tires, running in a vertical loop. The wheel bogies are guided by two concentric sets of steel guide rails. When a bogie runs along the bottom section of the rails, the tires are pushed down onto the pavement by a hydraulic and compressed nitrogen gas system. MLS10 can apply a maximum load of 30,000 lb per axle at a speed of about 12 mph *(38)*.

University of Costa Rica (LANAMME-UCR) - 2012

The University of Costa Rica initiated their APT program in 2012. The APT program also includes the construction of enclosed facility with eight test tracks and moisture control capabilities within the unbound layers.

Mexican Institute of Transportation (IMT) - 2015

To improve their pavement design and construction practices, the Mexican Institute of Transportation (IMT) implemented an APT program in 2015. The acquisition of the HVS was done through a national roadway construction and management concession project.

Virginia - 2015
The Virginia Department of Transportation (VDOT) initiated its APT program in 2015. It is housed at the Virginia Tech Transportation Institute (VTTI), in Vicksburg. An HVS Mark VI is used as the loading device.

CLOSING REMARKS
Since the early test track in Detroit in 1909, the APT has experienced many evolutionary milestones. Major investments have been and continue to be committed worldwide. Undoubtedly, APT has successfully been used to gain insight into new pavement technologies and design methods that laboratory testing alone would not provide. It has resulted in significant innovations and advances in pavement engineering knowledge and practices as well as providing critical information to policy makers. Moreover, specific economic benefits have been reported both in tangible and non-tangible less-quantifiable terms.

The Transportation Research Board (TRB) of the National Academies of Sciences, Engineering, and Medicine, known then as the Highway Research Board of the National Academy of Sciences, not only administered some of the early road tests including the historic AASHO Road Test but also played a quintessential role reporting and disseminating their findings. It also responded to the renewed and growing interest in APT by forming a Task Force (A2B52) in 1996 with the objectives of summarizing APT activities, evaluating and outlining recommended approaches for APT, and improving the communication and flow of information regarding APT. In 2001, this Task Force then became a full committee that is currently known as AFD40 Committee on Full Scale Accelerated Pavement Testing. This Committee, since its inception initially as a Task force, has sought to provide leadership, to encourage cooperation, and to further the global awareness of accelerated pavement testing through improved communication and information exchange on an international level.

In-service experimental set ups to assess emerging and innovative technologies is lengthy and, often difficult, impractical, and/or expensive. As governments struggle with budgets for infrastructure investment and renewal, APT provides for faster and more practical evaluation methods of emerging and innovative technologies under closely simulated in-service conditions. Ultimately, APT is still about performance and economics.

REFERENCES

1. Ray, G. K. History and Development of Concrete Pavement Design. *Journal of the Highway Division*, 1964. 90: 79-104.
2. Hines, E. N. The Concrete Roads of Wayne County, Michigan. *ACI Journal Proceedings*, 1913. 9: 462-469.
3. Beck, J. P., ed. *Proceedings of National Conference on Concrete Road Buildings*. Cement Products Exhibition Co., Chicago, 1914.
4. Collins, H. J., and C. A. Hart. *Principle of Road Engineering*. Edward Arnold Publishers, London, 1936.
5. Older, C. Bates *Experimental Road or Highway Research in Illinois*. Issue 21 of Bulletin. State of Illinois, Department of Public Works and Buildings, Division of Highways, 1924.
6. Bates Test Road. American Concrete Pavement Association. http://explorer.acpa.org/explorer/places/united-states/illinois/new-berlin/highway/old-us-54-bates-road-test/. Accessed Dec. 28, 2018.
7. Aldrich, L., and J. B. Leonard. *Report of Highway Research at Pittsburg, California, 1921 and 1922*. California State Printing Office, Sacramento, 1923.
8. American Concrete Pavement Association. *Evolution of Design*. http://overlays.acpa.org/Concrete_Pavement/About_Concrete/Evolution_of_Design/index.asp. Accessed May 30, 2018.
9. Pavement Interactive. *Pavement History*. https://www.pavementinteractive.org/reference-desk/pavement-types-and-history/pavement-history/. Accessed May 30, 2018.
10. Finney, E. A. *Report on Maryland Road Test One-MD.* Report No. 159, Michigan State Highway Department, Testing and Research Division, 1951.
11. National Research Council, Highway Research Board. *Final Report on Road Test One-MD: Effect of Controlled Truck Axle Loadings on Concrete Pavement*. Special Report 4 Publication 227, 1952. http://onlinepubs.trb.org/Onlinepubs/sr/sr4.pdf. Accessed May 30, 2018.
12. National Research Council, Highway Research Board. *The WASHO Road Test Part 1: Design, Construction, and Testing Procedures*. Special Report 18, Publication 310, 1955. http://onlinepubs.trb.org/Onlinepubs/sr/sr18.pdf. Accessed May 30, 2018.
13. National Research Council, Highway Research Board. *The WASHO Road Test Part 2: Test Data, Analyses, Findings*. Special Report 22, Publication 360, 1955. http://onlinepubs.trb.org/Onlinepubs/sr/sr18.pdf. Accessed May 30, 2018.
14. McKendrick, W. B., and W. N. Carey. *Status of Large Scale Road Tests.* AASHO Road Test, 1957. https://docs.lib.purdue.edu/cgi/viewcontent.cgi?referer=http://scholar.google.com/&httpsredir=1&article=2730&context=roadschool. Accessed May 30, 2018.
15. National Research Council, Highway Research Board. *The AASHO Road Test: History and Description of Project*. National Academy of Sciences-National Research Council, 1961.
16. Langsner, G., T. S. Huff, and W. J. Liddle. Use of Road Test Findings by AASHO Design Committee. Presented at Highway Research Board Conference on the AASHO Road Test, St. Louis, MO, 1962.
17. Hudson, W. R., C. L. Monismith, J. F. Shook, F. N. Finn, and E. L. Skok, Jr. AASHO Road Test Effect on Pavement Design and Evaluation after 50 Years. In *Transportation Research Circular E-C118: Pavement Lessons Learned from the AASHO Road Test and Performance*

of the Interstate Highway System, Transportation Research Board, Washington, D.C., 2017, pp. 17-30.
18. *AASHO Interim Guide for the Design of Flexible Pavement Structures*. American Association of State Highway and Transportation Officials, Washington, D.C., 1961.
19. *AASHO Interim Guide for the Design of Rigid Pavement Structures*. American Association of State Highway and Transportation Officials, Washington, D.C., 1962.
20. *AASHO Interim Guide for the Design of Pavements.* American Association of State Highway and Transportation Officials, Washington, D.C., 1972.
21. *AASHTO Guide for the Design of Pavements*. American Association of State Highway and Transportation Officials, Washington, D.C., 1993.
22. Coetzee, N. F., W. Nokes, C. Monismith, J. Metcalf, and J. Mahoney. Full-Scale/Accelerated Pavement Testing: Current Status and Future Directions. In *Transportation in the New Millennium*, Transportation Research Board, Washington, D.C., 2000.
23. Metcalf, J. B. *NCHRP Synthesis 235: Application of Full-Scale Accelerated Pavement Testing*. Transportation Research Board, Washington, D.C., 1996.
24. Theyse, H., M. De Beer, and F. Rust. Overview of South African Mechanistic Pavement Design Method. *Transportation Research Record: Journal of the Transportation Research Board*, 1996. 1539: 6-17.
25. Van Vuuren, D. J. *The Heavy Vehicle Simulator.* Shell Bitumen Review 41, London, UK, 1973.
26. Hugo, F., A. de Fortier Smit, and P. Warren. *Transportation Research Circular E-C118: Report on APT Data Survey.* Transportation Research Board, Washington, D.C., 1999.
27. Pidwerbesky, B. D. Relating Strain Response and Performance of Flexible Pavements under Accelerated Loading at CAPTIF. Presented at the 17th ARRB Conference, Gold Coast, Queensland, Australia, 1994.
28. Metcalf, J. B., J. R. McLean, and P. Kadar. The Development and Implementation of the Australian Accelerated Loading Facility Program. *Transportation Research Record: Journal of the Transportation Research Board*, 1986. 1060: 98-104.
29. De Boissoudy, A. Les objectifs d'un manège de fatigue dans le cadre de la recherche routière française. International Colloquium on Full Scale Pavement Test, Zurich, Switzerland, May 1982, pp. 35-53.
30. Wynand, S. Synthesis of Highway Practice 433: Significant Findings from Full-Scale Accelerated Pavement Testing. Transportation Research Board of the National Academies, Washington D.C., 2012.
31. Mitchell, T. *Westrack: The Road to Solutions.* Public Road, Vol. 60, No. 2, 1996. https://www.fhwa.dot.gov/publications/publicroads/96fall/p96au23.cfm. Accessed May 30, 2018.
32. Highway Technet. *West Track Performance Testing for Quality Roads.* https://library.unt.edu/gpo/OTA/pubs/superpave/westrack.html. Accessed May 30, 2018.
33. Brown, E. R., and R. B. Powell. A General Overview of Research Efforts at the NCAT Pavement Test Track. Presented at 2nd International Symposium on Maintenance and Rehabilitation of Pavements and Technological Control, Auburn, AL, 2001.
34. White, T. D., J. M. Albers, and J. E. Haddock. Limiting Design Parameters for Accelerated Pavement Testing System. *Journal of Transportation Engineering*, 1992. 118: 787-804.

35. Byron, T., B. Choubane, and M. Tia, Assessing Appropriate Loading Configuration in Accelerated Pavement Testing. Presented at 2nd International Conference on Accelerated Pavement Testing, Minneapolis, MN, 2004.
36. Transportation Engineering Program. *Accelerated Testing Facility (ATLAS)*. Department of Civil and Environmental Engineering, University of Illinois, Urbana Champagne. http://transportation-engineering.ict.illinois.edu/facilities/accelerated_testing_facility.html. Accessed June 11, 2018.
37. Greene, J., and B. Choubane. A Ten-Year Review of Florida's Accelerated Pavement Testing Program. In *Advances in Pavement Design through Full-scale Accelerated Pavement Testing* (D. Jones, J. Harvey, I. L. Al-Qadi, and A. Mateos, eds.), Taylor & Francis Group, London, UK, 2012, pp. 88-122.
38. Full-Scale Accelerated Pavement Testing (AFD40). Transportation Research Board Committee. *APT Facilities in Europe.* https://sites.google.com/site/afd40web/apt-facilities-outside-the-usa/europe. Accessed June 11, 2018.